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TWO YEAR TOPICAL INDEX

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INDEX TO AUTHORS

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OUTLINE KEY TO TOPICAL INDEX

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THIS Index, as well as the previous indexes, is arranged according to the topical classification of subjects. The original scheme for this method of indexing was published in the Journal for February, 1906. All articles which have appeared in the Journal since its initial issue can be located quickly by the use of the Ten-Year Index, (1904-1913), the Five Year Index (1914-1918) and the present Index, which covers the first two years of the fourth pentad.

Abbreviations: *T*—Number of Tables; *C*—Number of Curves; *D*—Number of Diagrams; *I*—Number of Illustrations; *W*—Number of Words; *QB*—Question Box; *EN*—Engineering Notes; *EH*—Industrial Applications of Electric Heaters; *ROD*—Railway Operating Data. (The numerals following *EN*, *EH* and *ROD* are volume and page numbers.) The main headings and sub-divisions are as follows:—

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Chicago, Milwaukee & St. Paul Railroad Electrification

Inspiration is inevitably the cause of progress. To the boldness and vision of Mr. John D. Ryan, more than any other one man, the noteworthy electrification of the Chicago, Milwaukee & St. Paul Railroad owes its accomplishment. The harnessing of nature's resources in the development of the Montana Power Company, which serves an area equal to that of a small nation, has been remarkable. The availability and reliability of this power at a favorable price, coupled with the certainty with which the action of electrical apparatus could be predetermined, led to the decision for the electrification of a great stretch of railroad, 440 miles in extent, far surpassing the scope of any previous electrification. This is the most recently accomplished undertaking and the only extensive one operated independent from steam operation. The operating and traffic conditions allow of operation which permits the merit and advantage of electrified service to be developed to an unusual degree.

The technical requirements, specified with rare ability by the electrical engineering staff of the Railroad Company as to apparatus and detail of substations, transmission lines, trolley construction and locomotives, were most precise, so that the execution of this electrification has been unique in the perfection of its detail.

The maintenance and operation of the electrical equipment has been handled with exceptional skill by the Mechanical Department of the electrified section, so that it may be said that the operating staff on this electrification has been governed with direction more appropriate to electrified operation than has been generally obtained in the supplanting of steam service.

The absence of steam motive power and the conditions local to this section of the country, have been of assistance in securing this result. The reward for appropriate conditions in the use of electrical apparatus is magnificent. It may be said that overloading, abuse or neglect in the operation of this equipment have been entirely absent throughout its whole history. The technical result of this electrification has been, therefore, noteworthy. This condition, coupled with its bold scope, has led to an interest most far-reaching and has contributed greatly to the acceptance, universally, of the idea that the electrified railroad is always a better operating proposition than the steam operation which it may supplant. Furthermore, this electrification is understood to show distinct financial advantage, and the lessened burdens for coal supply and locomotive maintenance, emphasized especially by recent history, are welcomed with enthusiasm by railroad men.

An additional 220 miles of electrified road is now being put in operation, the line from Othello, Washington to Seattle and Tacoma. Extensive analysis of comparative design and experience led to a large part of their new requirement, including locomotives necessary for this expansion, being placed with the Westinghouse Company.

A series of articles, which commence in this issue, will describe this improved apparatus, which covers many unique features, and also represents the latest advance in design and application of the various types of apparatus. To a layman these descriptions may appear involved, but to the informed it is well known that the criterion for the selection of electrical apparatus is very largely determined by the perfection of its design, and to these this series of articles will especially appeal. They will, however, be of scarcely less interest from the viewpoint of general information, and should form a valuable contribution to the literature of the art of railroad electrification. F. H. SHEPHARD

Engineers Should Study Cost Accounting

The services of an engineer, trained to use the facts and principles of physical science with technical preciseness, are valuable in a money sense only in proportion to the aid they bring to commercial activity. We are told that the present is a "commercial age". As a matter of fact, commerce has existed as long as mankind. Men have always sold what they could spare and bought what others could spare. We are also told that the present is a "manufacturing age". Such a definition of our times still fails properly to differentiate them.

This is the age of standardized production in which raw materials are transported from the various parts of the earth where they originally exist, to the spot where productive machinery and skilled workmen are most highly organized for the creation of articles useful to mankind. By standardizing the various articles— viz. making vast numbers of them exactly alike— and thereby making possible the standardizing of the labor and machinery required for their production, they can be manufactured so cheaply that the expense of transportation over long distances of both raw material and manufactured articles becomes justifiable.

For present-day standardized production, raw material must be uniform in quality and machinery must be capable of continuous operation at high speed without breakdown or deviation from established shape and quality of product. This can only be done by engineering; that is accurate designing of the article required and of the machinery by which it is produced.

Before incurring the expense of design and installation of special machinery, the business man must know what will be the cost of the product so as to fix the selling price and obtain the market. To determine the cost of the product, cost accounting methods must supplement the scientific designing of the engineer. When the engineer does not understand cost accounting and the cost accountant does not understand engineering, the business man who employs them is liable to lose money. After a number of articles have been manufactured, and the business man learns from the accountant that they are costing more than estimated, he blames the engineer for making the mistake because he can easily check up the accountants figures but does not understand the engineers drawing nor the scientific language in which he explains them.

Probably the engineer made one mistake at least,—viz. failure to understand the language and methods of cost accounting. He hears little or nothing about it at the engineering school, and probably has received the impression that it is not worth his attention.

The accountant divides the cost of anything into three parts; material, labor and general expense. The engineer may understand how to measure quite accurately the first two; but is liable to overlook or at least not properly apply the last one. Time is a ruling factor in general expense, for the greater part of such expense is continuous, not intermittent as is the cost of labor. Productive tools which work continuously should carry a smaller proportion of the general expense per month than those which work only occasionally.

The construction engineer who deals with the design and construction of railroads, buildings, dams, waterworks, etc. must be able correctly to estimate costs, if he is to be useful in a business sense; the same can be said of the research engineer, the sales engineer and even of the teacher of engineering; all must understand accounting to have the commercial value to which their knowledge apparently entitles them.

The study of a comprehensive modern work on accounting is the first step. When general principles and terms and methods are clearly understood, a special work on cost accounting dealing with the particular business in which the engineer is most interested should be studied and, if possible, a cost system actually in use should be analysed. Any good reference library can supply the books and the time consumed in such study will pay handsome dividends.

Engineers should learn what profit actually is and incidently how hard it is to obtain. They should learn to talk to the busines man in the language he understands.

SAMUEL E. DUFF

Making Electrical Connections

An expert electrician may work along with men in other engineering lines and appear to be doing work of a quite similar nature. For instance in equipping a central station or a new factory, he will work with steam turbine and steam boiler men, crane builders, structural steel workers, machine tool men, etc., and his fellow-workers can understand much of this work as being similar to their own. But when it comes to connecting apparatus, meters, transformers, switchboards, etc., the average mechanical man becomes lost in the mysteries of electricity. He is accustomed to dealing with visible, tangible quantities; but the truly electrical expert has a vision in his mind on which he bases his actions. He can see stars and deltas, polyphase circuits loaded with harmonic waves, vector relations with their out-of-phase or wattless components—things which have no real existence at all but which, for the purposes of the electrical expert, form the practice-based-on-theory by which he is able to go about his work with the assurance that, on its completion, he will most assuredly get the results desired. As success or failure may depend on this ability to carry in mind an image of electrical possibilities, it is vitally important that all electrical engineers have a good fundamental understanding of the most approved practice, based on long experience. The solution of electrical circuit problems, while comparatively simple in the more usual commercial forms, may become very complex and necessitate a thorough grounding in the fundamentals of transformer action and vector analysis.

Eleven years ago a series of articles was published in the JOURNAL on "Meter and Relay Connections" which proved to be of great value to our readers. While the fundamental facts are still the same, there have been many developments during the succeeding years, new apparatus has been designed and improved methods of analysis have come into general use. It has therefore been thought advisable to arrange for another series, along somewhat similar lines, written in view of the latest practice. The initial section of this series of articles, by Mr. J. C. Group, appears in the present issue of the JOURNAL.

This first section introduces the fundamental assumptions and conventional symbols which are used throughout the series. To secure a clear and easy understanding of subsequent articles, it is essential that author and reader be in agreement as to methods of representing alternating-current units, both in conventions as to circuits and aparatus details and as to vector diagrams. A standard method of vector representation is used, along the general lines originally described in the JOURNAL for September 1907 by Chas. H. Porter. This method of notation is based on marking every junction and terminal on the diagram of connections and on the use of two subscripts with every vector of current or electromotive-force, and serves to tie the connection and the vector diagrams together. It indicates not only angular positions of the vectors but positive and negative directions as well.

In the succeeding sections, it is planned to explain approved connections for various combinations of single and polyphase circuits, with details as to the inclusion of suitable transformers and instruments for the measurement and control of power under a great variety of conditions.

A. H. MCINTIRE

The Electric Power Supply for the Puget Sound Lines of the Chicago, Milwaukee & St. Paul Railroad

A. W. Copley

THE electrification of the Puget Sound lines of the Chicago, Milwaukee & St. Paul Railroad, which is now being put into operation, covers the Pacific and the Columbia River divisions and extends from Othello to Seattle and Tacoma, Washington. It does not connect with the electrification of the Missoula and Rocky Mountain divisions, as there is a gap of about 200 miles where steam operation is being continued. The power supply for the eastern lines (the Missoula and Rocky Mountain Divisions) is obtained from the Montana Power Company, with its large water power developments on the Missouri and Clark Fork Rivers. The power supply for the new electrification is obtained from the Intermountain Power Company, which buys power from the Washington Water Power Company and the Puget Sound Traction Light & Power Company. As these companies have large water power developments, the entire electrification can be said to be operated without the use of coal or oil fuel.

FIG. 1—LONG LAKE PLANT OF THE WASHINGTON WATER POWER COMPANY
Having a total capacity of 65 000 hp.*

Power for the Pacific and Columbia River Divisions is delivered to the railroad at three points (four ultimately) and in order to distribute the power to the eight substations, a transmission line has been built by the railroad on its right of way from Taunton to Cedar Falls, and another from Renton to Tacoma. Both of these lines are built with 110 000 volt construction. The eight substations are located at Taunton, Doris, Kittitas, Cle-Elum, Hyak, Cedar Falls, Renton, and Tacoma. At each of these the power is transformed to 2300 volts, which is applied to the motors of the motor-generator sets, 3000 volts, direct current being obtained from the generators. Power is supplied at this voltage to the trolley.

The railroad transmission line between Taunton and Cedar Falls is 141 miles long. It is similar in its construction to the line which has been in service on the Rocky Mountain and Missoula divisions, the principal modification being the fact that transpositions, coordinated with those of the neighboring telephone lines, have been introduced,. in order to reduce as far as possible inductive interference from this part of the system. Single poles with two cross-arms are used. The upper arm supports at one end a 3/8 inch steel ground wire and at the other end a 00 stranded copper

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*Figs. 1, 2, 5, 9, 10 and 13 furnished through the courtesy of the *Stone & Webster Journal*, Boston, Mass.

conductor with hemp core. The other 00 line conductors are suspended from the ends of the lower arm. This gives a spacing of the conductors in the form of a right-angle triangle with a base of 10 ft. 2 inches and an altitude of 9 ft. A diagram of the high-tension system showing the transpositions is shown in Fig. 8. There is one complete "barrel" between Tacoma and Renton (a distance of about 27 miles) and another between Renton and Snoqualmie (about 21 miles), the ground wire being changed from one end of the upper arm to the other at Renton. Between Snoqualmie and Taunton there are two transpositions, one at Cedar Falls and another at Kittitas. These two transpositions affect only the diagonally opposite conductors, which are interchanged at the transposition points.

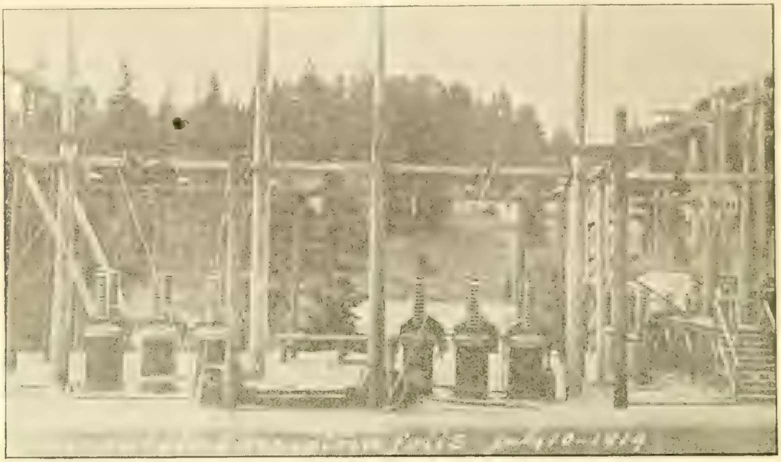


FIG. 2—OUTDOOR SUBSTATION AT SNOQUALMIE, SHOWING LINE SWITCHES

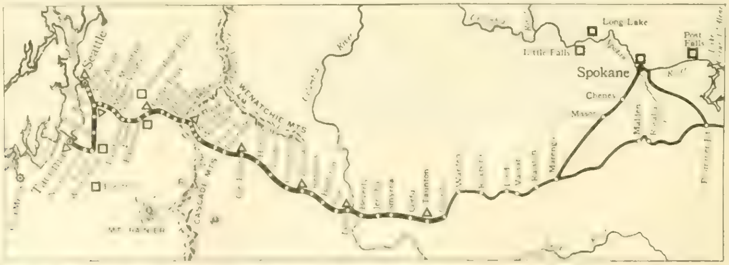


FIG. 3—MAP OF RECENTLY ELECTRIFIED SECTION OF THE CHICAGO, MILWAUKEE & ST. PAUL RAILROAD
Showing location of substations (triangle) and hydroelectric stations (square) supplying power.

The 110 000 volt line may be sectionalized at any substation. At Taunton, Kittitas, Hyak and Cedar Falls, sectionalization is accomplished by the use of oil circuit breakers provided with power directional relays, so set as to cut out only the affected section in case of a short-circuit or ground. At Doris and Cle-Elum, horn-gap disconnecting switches are used for sectionalization and these are non-automatic. When the line is opened at any of these stations, the power plants of the Washington Water Power Company and the Puget Sound Traction Light & Power Company are entirely separated and must be synchronized before the sectionalizing circuit breakers may be closed again. Synchronizing is accomplished at the substation at which the line has been opened. The plant which will supply the power from the Washington Water Power Company is located at Long Lake on the Spokane River. This is connected to feed the railroad transmission circuit by a 110 000 volt, three-phase line, 113 miles long. This line uses the wood pole "H" frame construction, giving a horizontal spacing of the conductors of 10 ft. 6 in. Six suspension insulators are used for each string. A 3/8 inch steel ground wire is supported on the tops of the poles above the transmission wires for lightning protection. The line conductor is 115 500 circ. mil 7-strand copper. In the Long Lake plant there are three 19 500 kv-a. three-phase, 60 cycle, 4000 volt generators and three banks of 6500 kw, single-phase, step-up transformers. These are connected delta-delta for 63 000 volts high-tension or delta-star to give 110 000 volts. One spare transformer unit is installed. The tie lines between the other plants of the Washington Water Power Company are operated at 63 000 volts, but at Long Lake one generator and bank of transformers are connected to supply the 110 000 volt cir-

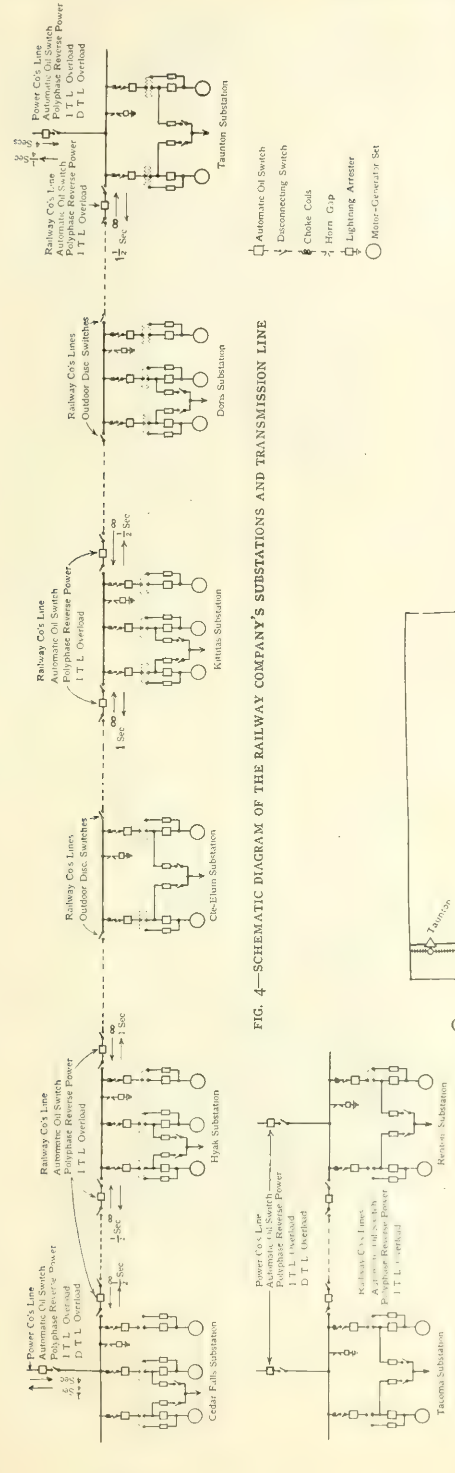


FIG. 4—SCHEMATIC DIAGRAM OF THE RAILWAY COMPANY'S SUBSTATIONS AND TRANSMISSION LINE

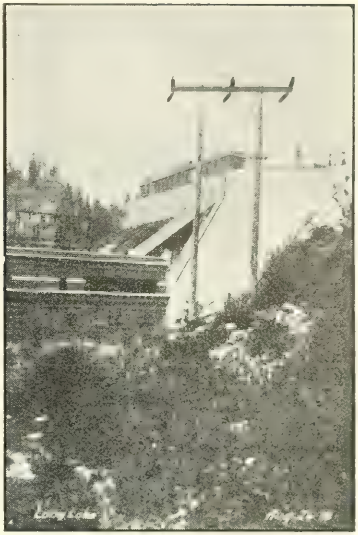


FIG. 5—GATE HOUSE, PENSTOCK AND TRANSMISSION LINE AT LONG LAKE PLANT

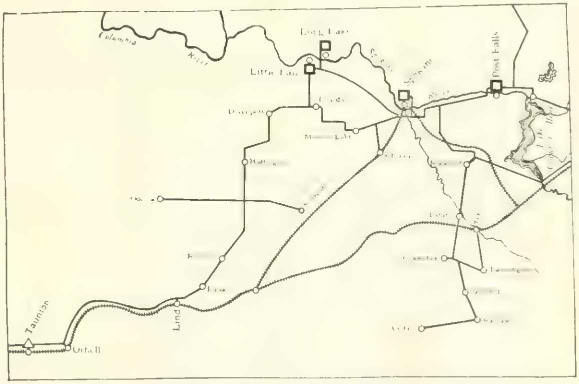


FIG. 6—LOCATION OF HYDRO-ELECTRIC SUBSTATIONS AND HIGH TENSION TRANSMISSION LINE

Of the Washington Water Power Company and of the Intermountain Power Company, connecting with the Railway Company's transmission line at Taunton.

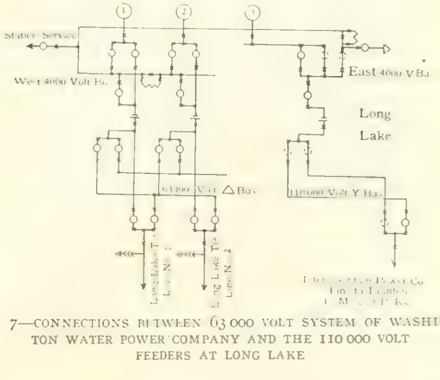
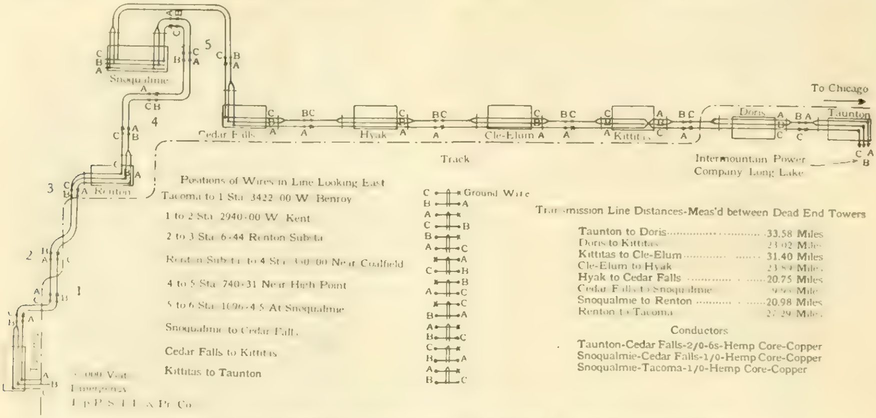


FIG. 7—CONNECTIONS BETWEEN 63 000 VOLT SYSTEM OF WASHINGTON WATER POWER COMPANY AND THE 110 000 VOLT FEEDERS AT LONG LAKE

cuit to the railroad. There is a 4000 volt transfer bus in the station so that any generator can be connected to any transformer bank as an insurance of continuous service. When the generators are all operated on the bus, ten percent reactors are connected between the bus sections.

It is also possible to supply the railroad transmission line with power from Little Falls or Post Falls by stepping down from 63 000 volts at Long Lake to the 4000 volt bus and then up to 110 000 volts through the regular generator transformers. At Little Falls there are four generators, three of them being rated at 6250 kv-a. and one at 6900 kv-a. These connect to three-phase transformers, stepping up from 4000 volts to 63 000 volts with grounded neutral on the high-tension side. At Post Falls, five 2250 kv-a. generators and six three-phase transformers (with one spare) are installed. In addition to these plants a steam plant in Spokane can be connected to the 63 000 volt system, but ordinarily it is not so connected.



To Chicago
Snoqualmie
Cedar Falls
Hyak
Cle-Elum
Kittitas
Doris
Taunton
Renton
Track
Intermountain Power Company Long Lake
1
2
3
4
5
Positions of Wires in Line Looking East
Tacoma to 1 Sta. 3422+00 W. Benroy
1 to 2 Sta. 2940+00 W. Kent
2 to 3 Sta. 6+44 Renton Substa.
Renton Substa. to 4 Sta. 350+00 Near Coalfield
4 to 5 Sta. 740+31 Near High Point
5 to 6 Sta. 1096+4.5 At Snoqualmie
Snoqualmie to Cedar Falls
Cedar Falls to Kittitas
Kittitas to Taunton
Ground Wire
Transmission Line Distances-Meas'd between Dead End Towers
Taunton to Doris 33.58 Miles
Doris to Kittitas 23.02 Miles
Kittitas to Cle-Elum 31.40 Miles
Cle-Elum to Hyak 23.84 Miles
Hyak to Cedar Falls 20.75 Miles
Cedar Falls to Snoqualmie 9.96 Miles
Snoqualmie to Renton 20.98 Miles
Renton to Tacoma 27.29 Miles
Conductors
Taunton-Cedar Falls-2/0-6s-Hemp Core-Copper
Snoqualmie-Cedar Falls-1/0-Hemp Core-Copper
Snoqualmie-Tacoma-1/0-Hemp Core-Copper
Tacoma Sub Sta. P. S. T. L. & P. Co.

FIG. 8—TRANSPOSITION SCHEME OF THE RAILWAY COMPANY'S 110 000 VOLT SYSTEM

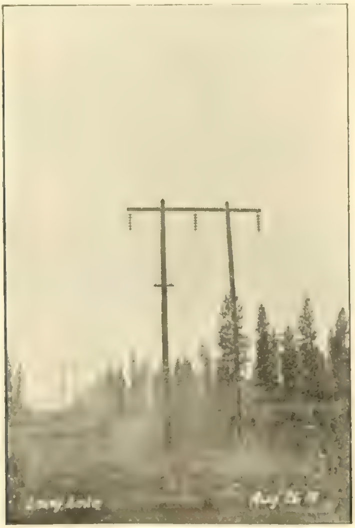


FIG. 9—TYPICAL LINE CONSTRUCTION OF THE INTERMOUNTAIN POWER COMPANY

Telephone wires are carried on the lower cross arms.

At the western end of the electrification, power is supplied from the plants of the Puget Sound Traction Light & Power Company, connections being made through a bank of 4500 kv-a. transformers at the Intermountain Power Company's substation, located at Snoqualmie. One transmission line at 110 000 volts runs from here to Cedar Falls and another from here to Renton. These lines are built with the same construction as used on the railroad transmission lines, except that the conductor is No. 0 stranded copper, with hemp core. Eventually power will also be supplied directly to the Tacoma substation but, at present, power for this station comes from Renton over the railroad transmission line.

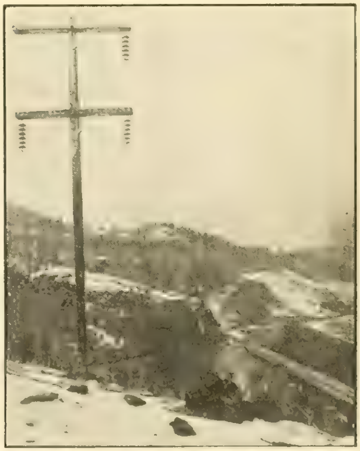


FIG. 10—110 000 VOLT RAILWAY COMPANY TRANSMISSION LINE

At a high point on the line. This shows the double arm construction and the stranded steel ground wire on the left end of the upper cross arm.

The power which can be supplied to the feeders at Snoqualmie consists of the Snoqualmie plant, with 18 000 kw capacity, the White River plant with 52 000 kw, the Electron plant with 14 000 kw, together with the steam plants in the City of Seattle. At times, however, it is expected that power will be fed in the reverse direction over the Cedar Falls feeder, with the Washington Water Power Company supplying some of the Puget Sound Traction Light & Power Company's load over the Railroad company's transmission line.

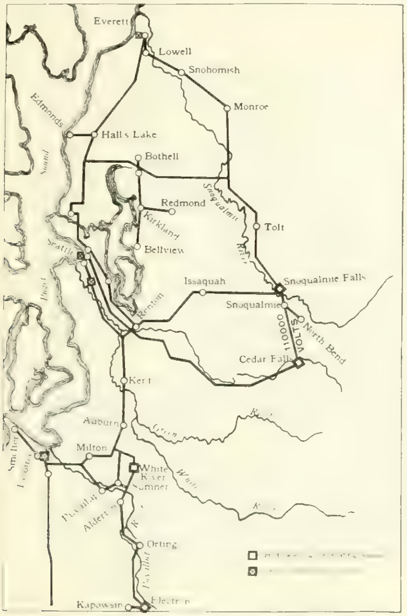


FIG. 11—LOCATION OF HYDRO-ELECTRIC SUBSTATIONS AND HIGH-TENSION TRANSMISSION LINES OF THE PUGET SOUND TRACTION, LIGHT AND POWER COMPANY'S SYSTEM

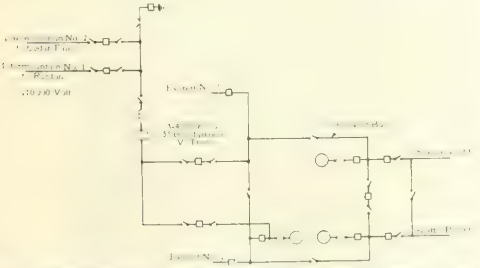


FIG. 12—CONNECTIONS BETWEEN THE 55 000 VOLT SYSTEM OF THE PUGET SOUND TRACTION, LIGHT & POWER COMPANY AND THE 110 000 VOLT FEEDERS AT SNOQUALMIE

At Tacoma and Renton substations the transformers are arranged for operation at either 55 000 or 110 000 volts. A power tap is provided at Tacoma which can, for emergency service, be connected to the 55 000 volt system of the Puget Sound Traction Light & Power Company at that point. This provides for power in an emergency, if the 110 000 volt transmission from Snoqualmie should be out of commission.

While this transmission line is nominally rated at 110 000 volts, and the Long Lake transformer is connected for 110 000 volts, the transformers at Snoqualmie are connected for 95 000 volts. This holds up the power-factor at Long Lake at times when no load is taken by the Snoqualmie plant. When only the transmission line is connected to the Long Lake plant, the high-tension voltage there is 115 000, and at the Snoqualmie end of the line it is 128 000, the potential rise being caused by the line charging current. Closing the switch to connect the transmission line to the

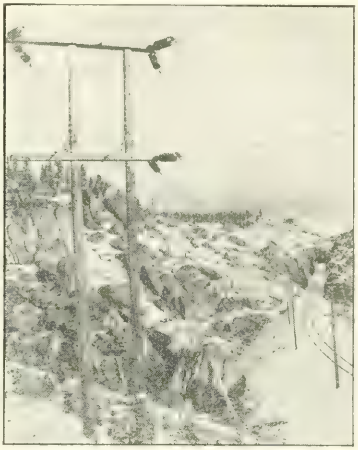


FIG. 13—SPECIAL CONSTRUCTION OF THE 110 000 VOLT RAILWAY COMPANY TRANSMISSION LINE

At an angle point, having a span of 675 feet.

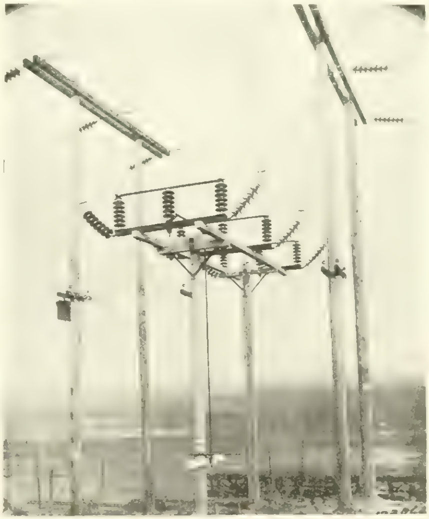


FIG. 14—110 000 VOLT POLE TOP SWITCH AT TAUNTON

95 000 volt taps on the Snoqualmie transformers, gives 101 000 volts at Snoqualmie. If Snoqualmie takes 10 000 kw from Long Lake, the voltage at Snoqualmie drops to 99 000 volts.

The substation equipments include 2500 kv-a. step-down transformers, and 2000 kw motor-generator sets, each set consisting of a 2300 volt, three-phase, 60 cycle synchronous motor driving two 1500 volt, direct-current generators, which are connected in series to obtain 3000 volts. Initially each substation contains two transformer and motor-generator set units, except at Cle-Elum and Renton, where only one set is installed at present. Provision is made for additional units at these stations and also at Doris, Kittitas, Hyak and Cedar Falls.

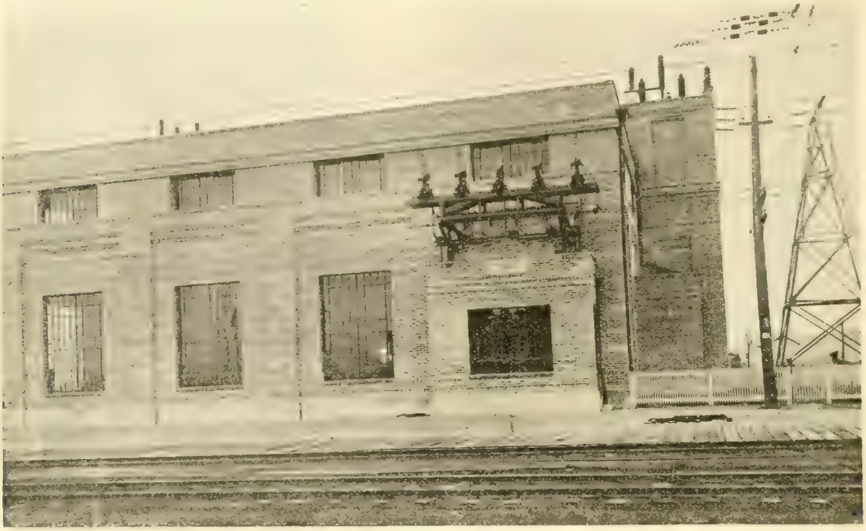


FIG. 15—SUBSTATION NO. 23

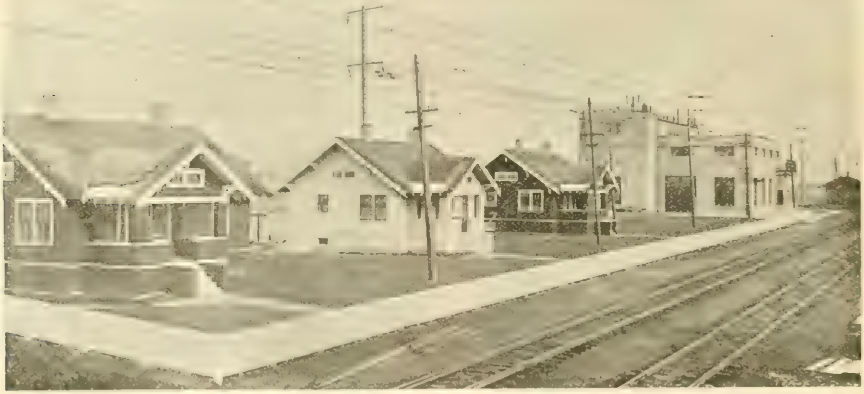


FIG. 16—VIEW OF KITTITA[illegible]ON, TROLLEY CONSTRUCTION, TRANSMISSION LINE AND COMPANY RESIDENCES

Equipment for the substations is being supplied by the Westinghouse Electric & Mfg. Company and the General Electric Company. Each of these companies has taken special precautions to guard against the occurrence of flash-overs on the direct-current generators at times of short-circuit on the 3000 volt system. The substations whose equipment is supplied by the General Electric Company are provided with high-speed circuit breakers with a view to opening the circuit before the current has had opportunity to build up. The machines furnished by the Westinghouse Company are protected by the "flash suppressor", a device developed especially for this electrification. It has been proven in service and has been found to meet fully the requirements.

The contract between the Intermountain Power Company and the Chicago, Milwaukee & St. Paul Railroad specifies that the total demand of the Railway Company must not exceed a stated amount when integrated over a period of five minutes, and that the power payment be based upon this amount, with a maximum load factor of 60 percent. For instance, if the denominated maximum is 10 000 kw, the Railway Company will pay for 6000 kw integrated over the month, whether this amount is used or not, and for amounts in excess of 6000 kw will pay at the same rate per kw-hr. This requirement gives the Railway Company the benefits in cost of power generation that accrue because of high load factor. In order to meet the conditions of the contract it becomes necessary to totalize at every instant the whole load being taken into the railway system at the substations located at Taunton, Cedar Falls, Renton and eventually Tacoma. This load must be totalized in such manner that it can be measured by a maximum demand meter with a five minute interval, as well as indicated and recorded. Also, in order to prevent the peaks of load usual to railway service from penalizing the road in additional power cost, the voltage generated at the substations is reduced automatically when the total load reaches such proportions that the nominated maximum demand is in danger of being exceeded. The result is a smoothing out of the load curve of the system by slowing down trains during the peak and spreading some of this load over the valleys of the curve.

Transformer Equipment

For the Chicago, Milwaukee & St. Paul Installation

WALTER M. DANN

THE motor-generator sets that supply direct-current to the Chicago, Milwaukee & St. Paul locomotives are connected to the 100 000 volt alternating-current lines through three-phase substation transformers, having a rating of 2500 kv-a. Each motor-generator set, with its motor rated at 2420 kv-a., is fed by its own three-phase transformer, making a complete transforming unit from the high-voltage alternating-current lines to the 3000 volt direct-current circuits.

These substation transformers are self-cooling, i.e., they dissipate the heat due to their losses without depending upon circulated water or forced air. One of the features that marks the installation as being different from many recent installations is the form of the case. Instead of being provided with external radiators, as most large self-cooling transformers now are, the oil circulates and is cooled through a large number of external tubes, extending from the top to the bottom of the case. This form of self-cooling case is very rugged and substantial, and quite efficient in its heat dissipating qualities. It is more expensive than the radiator type case but it is compact, and requires considerably less floor space. In these substations, the use of the tubular tanks resulted in savings in the cost of the buildings which offset the extra cost of the transformers.

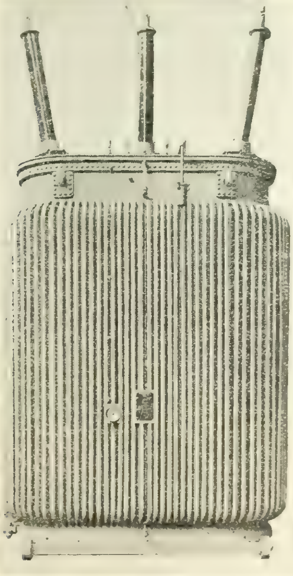


FIG. 1—25 000 KV-A. OIL INSULATED SELF-COOLING TRANSFORMER

FIG. 2—GROUP OF TRANSFORMERS INSTALLED IN THE DORIS SUBSTATION

Railway electrification service makes certain demands on the apparatus which are quite different from the service requirements for the usual power transformer installation. Starting and accelerating the locomotives and the movement of trains toward and away from the points from which the power is fed produce great fluctuations of loading at those points. In order to provide adequate capacity for these fluctuations, the Chicago, Milwaukee & St. Paul transformers are required to carry their full loads continuously with rise of temperature not exceeding 40 degrees C, followed by 150 percent load for two hours without exceeding a rise of 60 degrees C. In order to take care of short-time swings of greater magnitude, they are also required to carry 300 percent load for five minutes, following the 150 percent load condition, without reaching a dangerous temperature. The motor-generator sets, of course, have corresponding overload capacities.

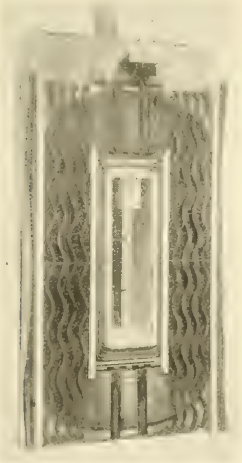


FIG. 3—SECTION THROUGH A GROUP OF HIGH-VOLTAGE COILS
Showing the spacing strips and oil ducts.

The heat developed in the windings at 300 percent load is nine times as great as at full load. A considerably quickened flow of oil becomes necessary to carry away the heat generated under such conditions. Accordingly, the coils must be interspersed with numerous ducts of ample size to allow the oil to circulate with the least possible interference, and in that way maintain, as closely as possible, an even temperature throughout the windings. This is important to a high degree in transformers for railway electrification. Fig. 3 illustrates how the oil ducts are formed by means of curved spacing strips which separate the coils and leave oil duct spaces between them. The oil flows upward in the natural direction over the faces of the coils with very little hindrance, and the curved ducts make it possible for it to come into contact with all of the conductors of the coils.

Another phase of railway service which calls for careful design of the apparatus is the likelihood of more frequent short-circuits than in the case of the ordinary power house or substation. A decade or so ago, the magnitudes of the mechanical forces that develop in transformer windings at the time of short-circuit were not as fully comprehended as they are at the present time. Now, it is very generally recognized that they may become tremendous, and a transformer designed without regard to the size of the forces and the directions in which they act would not last long on a present-day system where heavy short-circuits may occur frequently.

These substation transformers, one of which is shown out of its case in Fig. 4, were designed with particular regard to the mechanical stresses that develop on short-circuit. The shell form of construction was used. By the arrangement of the coils and the number of turns in the coils, the forces of repulsion between the primary and secondary coils due to the ampere-turns of the windings under normal full-load conditions were kept very low. Consequently, these forces under short-circuit conditions are very much smaller than usual in power transformers, notwithstanding the fact that they increase with the square of the current. The steel plates at the tops and bottoms of the coils, which brace them against the forces tending to separate the primary and secondary coils, are comparatively light because of the small active forces. The impedance of the system between the transformers and the generators, including the generator impedance, naturally protects the transformers at times of short-circuit, by reducing the amount of current that can flow. However, the mechanical forces in these substation units are so small that they would withstand short-circuits if they were directly connected to a generating system having no impedance; i.e., a generating system of infinite capacity.

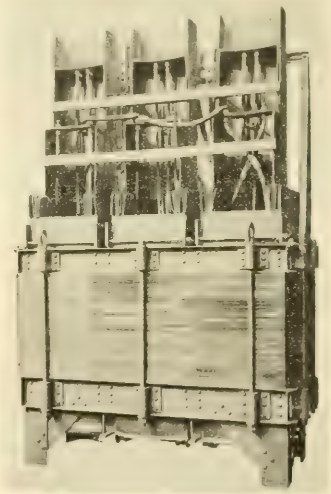
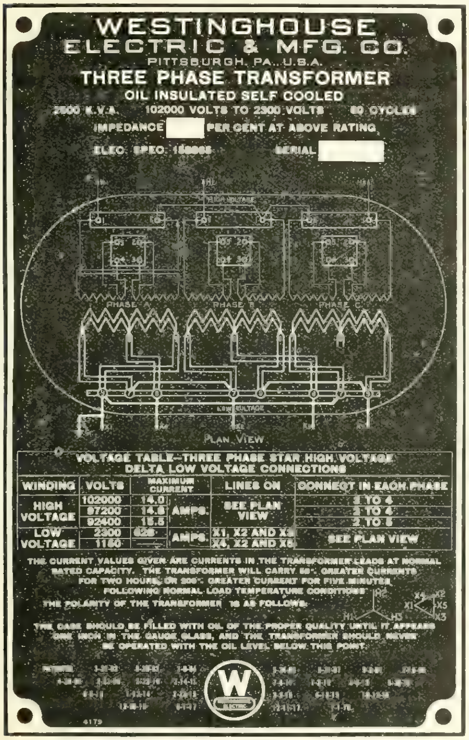


FIG. 4—TRANSFORMER OUT OF ITS CASE

The high-voltage windings of the transformers are connected in star and are designed for a line voltage of 102 000 volts. Two taps in this winding allow full output from the low voltage windings at full voltage if the line voltage drops 5 to 10 percent. The conductors of the high voltage coils next to the line leads and next to the neutral point are extra heavily insulated to guard against damage from line surges, and the taps are placed in the middle of the winding for the same reason. The high voltage windings received the standard A. I. E. E. insulation test of 205 000 volts for one minute. The high voltage bushings, which are of the well-known condenser type, received a test of 300,000 volts for one minute. Fig. 1 shows that these bushings are quite small and compact for the voltages involved. The design of this type of bushing, with its concentric condensers, is based on mathematically correct principles, which produce a practically uniform gradation of stress from the inner conductor to the outer surface.



WESTINGHOUSE
ELECTRIC & MFG. CO.
PITTSBURGH, PA., U.S.A.
THREE PHASE TRANSFORMER
OIL INSULATED SELF COOLED
2500 K.V.A. 102000 VOLTS TO 2300 VOLTS 60 CYCLES
IMPEDANCE [redacted] PER CENT AT ABOVE RATING
ELEC. SPEC. [illegible] SERIAL [redacted]

VOLTAGE TABLE—THREE PHASE STAR HIGH VOLTAGE
DELTA LOW VOLTAGE CONNECTIONS

WINDING	VOLTS	MAXIMUM CURRENT		LINES ON	CONNECT IN EACH PHASE
HIGH VOLTAGE	102000	14.0	AMPS.	SEE PLAN VIEW	3 TO 4
	97200	14.8			2 TO 4
	92400	15.5			2 TO 5
LOW VOLTAGE	2300	628	AMPS.	X1, X2 AND X3	SEE PLAN VIEW
	1150	—		X4, X2 AND X5	

THE CURRENT VALUES GIVEN ARE CURRENTS IN THE TRANSFORMER LEADS AT NORMAL RATED CAPACITY. THE TRANSFORMER WILL CARRY 50% GREATER CURRENTS FOR TWO HOURS, OR 200% GREATER CURRENT FOR FIVE MINUTES FOLLOWING NORMAL LOAD TEMPERATURE CONDITIONS.

THE POLARITY OF THE TRANSFORMER IS AS FOLLOWS:

THE CASE SHOULD BE FILLED WITH OIL OF THE PROPER QUALITY UNTIL IT APPEARS ONE INCH IN THE GAUGE GLASS, AND THE TRANSFORMER SHOULD NEVER BE OPERATED WITH THE OIL LEVEL BELOW THIS POINT.

4179

FIG. 5—TRANSFORMER NAME PLATE
Showing connections and location of taps.

The low-voltage windings are designed for 2300 volts and are connected in delta. The motor-generator sets are started at half normal voltage, obtained from one corner of the delta and half voltage taps in two of the phases. Fig. 5 shows one of the nameplates such as is mounted on each transformer. This plate shows the development of the windings and the connections between phases, as well as the ratios of transformation, so that detailed information regarding the interior arrangement of the transformer windings will always be available. The instrument mounted near the nameplate in Fig. 1 is a dial type thermometer which indicates the temperature of the oil. Its bulb, which is placed in the hottest oil at the top of the case, is connected to the instrument through the tubing shown in the illustration.

Arrangements have been made in the substations to store the oil from the transformers when it becomes desirable to remove it for any reason. A storage tank is placed under the floor level below each of the two transformers in the Doris, Kittitas and Taunton substations, as shown in Fig. 6. The storage tanks are connected together by piping and have a combined capacity of 3600 gallons. They are intended to provide storage capacity with ample margin for either transformer but not for both. Each transformer tank contains 2800 gallons of oil. The oil can be pumped from the storage tanks into the transformer tanks through a filter press.

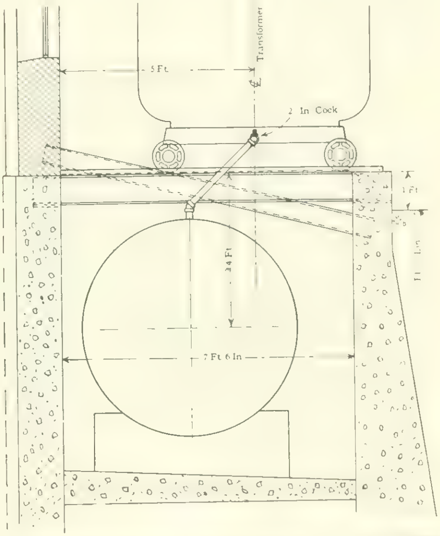


FIG. 6—ARRANGEMENT OF OIL TANKS FOR EMPTYING TRANSFORMERS

There are no cranes above the transformers in these substations. When a transformer is to be removed from its tank, it is rolled from position on its own wheels onto a truck which runs on rails placed at right angles with the transformer rails. The truck is then moved along these rails to the end of the room where an overhead crane is available for untanking the transformer.

3000 Volt Motor-Generator Sets

For the Chicago, Milwaukee & St. Paul Railroad

DAVID HALL

BETWEEN the water falls, which supply power to the great system of the Chicago, Milwaukee & St. Paul Railroad, and the electric locomotives which use this power in the moving of trains, there is no more important link than the motor-generator sets. Distributed as they are in suitable substations along the right-of-way, the motor-generator sets receive three-phase power at 2300 volts and deliver direct-current power to the electric locomotives at 3000 volts. The reverse is also automatically accomplished; that is, through the motor-generator sets direct-current power may be converted into alternating-current power when, on account of trains going down grade, it becomes necessary to brake them instead of pull them. At such times, the motors on the locomotives become generators, receiving mechanical energy due to the coasting action of the train; thus the electric locomotive serves as a brake and the power instead of being wasted in mechanical friction is delivered at approximately 3000 volts, to the generators of the motor generator sets, through which it is converted into alternating-current power and fed back into the system.

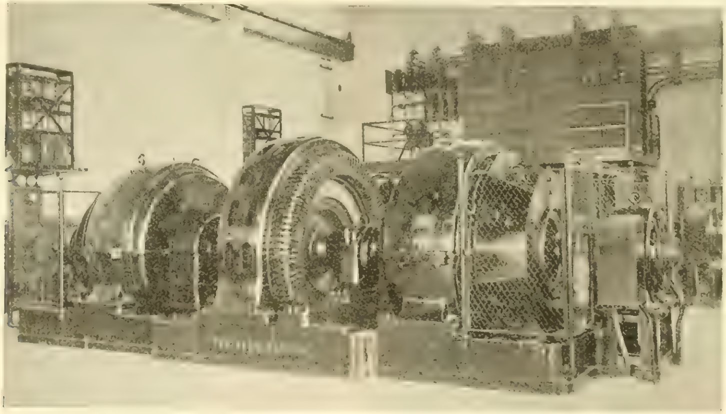


FIG. 1—THREE MACHINE MOTOR-GENERATOR SET INSTALLED IN THE KITTITAS SUBSTATION OF THE CHICAGO, MILWAUKEE & ST. PAUL RAILROAD

Rated at 6000 kw output for five minutes. Maximum momentary output 13 000 kw.

Each motor-generator set consists of a 2800 horse-power, three-phase, sixty cycle, 2300 volt, 514 r.p.m. synchronous motor which drives two direct-current, 1500 volt, shunt-wound, commutating-pole, compensated generators, the armatures of which are connected in series to give 3000 volts. The motor is located between the two generators as shown in Fig. 1, making a three machine set with two exciters, one for the motor and one for the generators.

These sets were designed to meet very rigorous specifications in conjunction with a number of special conditions which minimize losses and insure high efficiencies. While the set rating is only 2000 kw, the specifications require a capacity of 3000 kw, for two hours without exceeding 55 degrees C. rise and 6000 kw output for five minutes thereafter with safe temperatures. An examination of the heating data given in Table I will show considerable margin in capacity.

The synchronous motor of these sets is made with a very liberal capacity in the fields, in order that a high power-factor may be maintained over a wide range of load. Each motor is supplied with a special exciter, equipped with suitable field windings so that the desired power-factor is automatically obtained at all loads, both for motor and generator action. The motor is built entirely open and is sufficiently liberal in design to operate within the temperature guarantee without the use of fans, thus minimizing windage losses and improving efficiency. This fact, taken in conjunction with the special method of reducing the windage losses on the generators, enables the set to work at all times with a minimum of windage losses. The arrangement on the direct-current generators for reducing the windage is accomplished by building the machines partially enclosed, as shown in Fig. 2, with very little natural windage and provided with a separate blower, which operates only when the generators are carrying such loads as to require ventilation. As the two generators are always in series and carry equal loads they will always be at approximately the same temperature, hence one blower only is necessary per set. Each blower is automatically started and stopped by the action of a resistance coil, which is taped-up with a series conductor of one of the generators in such a manner that the temperature of the resistance coil will always be approximately the same as that of the armature.

The success of high-voltage, direct-current equipment may be said to hinge about commutation. Consequently in the design of these generators, great care was exercised to embody every feature which would assist in the obtaining of inherently good commutating characteristics. In the proper selection of these features rests the success of the design.

The voltage characteristics of these generators from zero current to twenty times full-load current are shown in Fig. 3. This curve was plotted from a complete series of oscillograph tests. Each point on the curve is taken from an oscillograph record, up to and including the point for twenty times full-load current, which is the maximum current obtainable on short-circuit. These short-circuit tests were made with the direct-current circuit grounded on the low-voltage side and with only a slow speed circuit breaker on the high-voltage side to open the circuit.

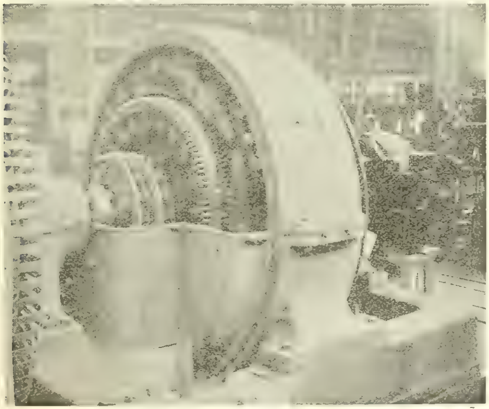


FIG. 2—DIRECT-CURRENT GENERATOR
With upper half of rear end bell removed.

That these machines successfully withstood a direct short-circuit without bucking is shown by Fig. 4. When making this test, the generators, operating at 3000 volts, were short-circuited with no resistance in the external circuit, except the necessary connections and circuit breaker; representing the greatest shock that it is possible to impose upon these generators. The oscillograph shown in Fig. 4 shows some interesting facts. From the moment of short-circuit, the current increased at the rate of about 1250 amperes per thousandth of a second, reaching 5000 amperes in 0.004 sec., 10 000 amperes in 0.010 sec. and a final current of 13 000 amperes in about 0.020 sec. The current remained at 13 000 amperes for about 0.045 sec. when the opening of the circuit breaker began to reduce it; the circuit being completely opened in one tenth of a second from the time of closing. The effect of the armature current upon the shunt field current and also on the external voltage is readily observable from the curve. The external voltage drops to zero when the short-circuit is applied and as the circuit opens, the external voltage builds up, momentarily reaching a voltage somewhat higher than normal.

TABLE I—ARMATURE TEMPERATURE RISES IN DEGREES C.

Percent Load	100	125	150
Without blower	28	40.5	56.5
With blower	24.5		47.5
Guarantees with blower ..	35		55

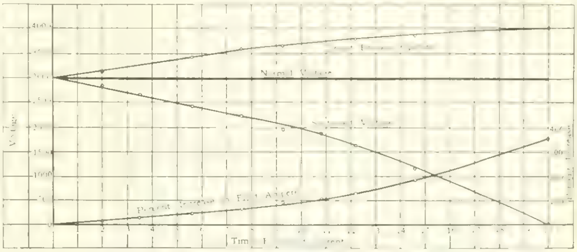


FIG. 3—DIRECT-CURRENT TERMINAL VOLTAGE CHARACTERISTICS
From zero current to 20 times full load current.

TABLE II—EFFICIENCIES OF MOTOR GENERATOR SETS

Percent Load	50	75	100	150
Test efficiency	89.5	91.9	92.9	93.4
Guaranteed efficiency ..	88.9	91.3	92.4	93.4

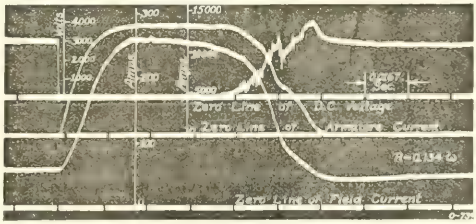
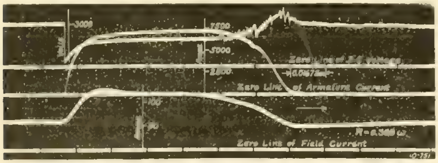
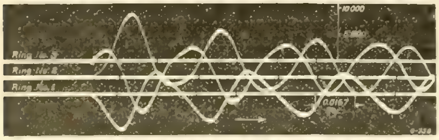


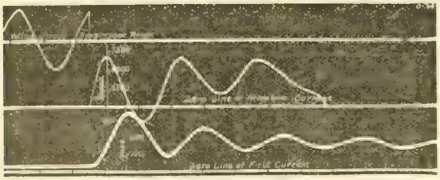
FIG. 4—OSCILLOGRAM OF SHORT-CIRCUIT TESTS AT 3000 VOLTS
The current reached twenty times normal without bucking.

Fig. 5 is added as a matter of interest to show the performance of the generators when short-circuited on a resistance such as to give approximately eleven times full-load current. A steady current of about 7200 amperes and a steady voltage of 1850 volts, or a true output of 13 000 kw was maintained for a fraction of a second, or until the circuit breaker opened the circuit, restoring the no-load conditions. This particular point represents the maximum kw output of the set as, with any less external resistance, the external voltage drops more rapidly than the current increases, all for a given initial condition of 3000 volts at no load. The machine withstood this test without either the radial or the outer flash-guards.

While all the above description and tests apply to these machines as normal, shunt wound generators, a further protective device for commutating machines, which has been recently worked out, has been supplied with these motor-generator sets. Everyone familiar with railway generating machinery has realized the desirability of some means of nullifying the voltage on the commutator of a direct-current machine when such conditions arise as might cause flashing. To this end a "flash suppressor" has been designed. This suppressor is simple and effective, and gives a protection to the generators which, regardless of how good the generators may be inherently, is in harmony with a safe and sane policy of supplying the maximum possible protection against break-down or failure of the apparatus.







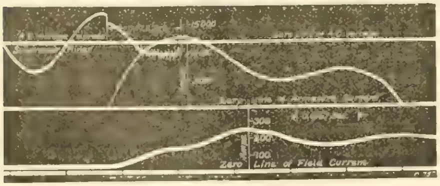


FIG. 5 (0 751)—OSCILLOGRAM OF SHORT CIRCUIT TEST AT MAXIMUM POSSIBLE LOAD

Showing a true kilowatt output of 13 000 kw.

FIG. 6 (0 758)—DIRECT-CURRENT MACHINE SHORT CIRCUITED ON THE ALTERNATING-CURRENT SIDE ONLY

FIG. 7 (0 764)—MACHINE SHORT CIRCUITED ON BOTH THE DIRECT AND ALTERNATING SIDES SIMULTANEOUSLY

FIG. 8 (0 757)—MACHINE SHORT CIRCUITED ON THE DIRECT-CURRENT SIDE WITH THE ALTERNATING SIDE SHORT CIRCUITED 0.022 SECONDS LATER

This protection consists of equipping the direct-current generators with three-phase collector rings and providing means for short-circuiting these rings, thus establishing currents inside the armature windings, absorbing the voltages generated and thereby relieving the commutators and brushes of the short-circuited currents which they would otherwise carry.

This action can best be followed by an examination of oscillograph records showing various conditions of operation. Fig. 6 shows the currents produced by short-circuiting the alternating-current rings only. Fig. 7 shows the results of short-circuiting the machine at both the direct-current and alternating-current end simultaneously, while Fig. 8 shows the effect of delaying the alternating-current short-circuiting 0.022 seconds after the instant of direct-current short-circuiting. Fig. 9 is a photograph of this machine taken at the time of the above described short-circuit. That is, the machine is shown under the stress of a dead short-circuit, the direct-current reaching 13 000 amperes, when the machine is automatically short-circuited on the alternating-current side, the internal reactions quickly reducing the external current to zero, thus relieving the commutator and the commutator brushes of all loads or stresses.

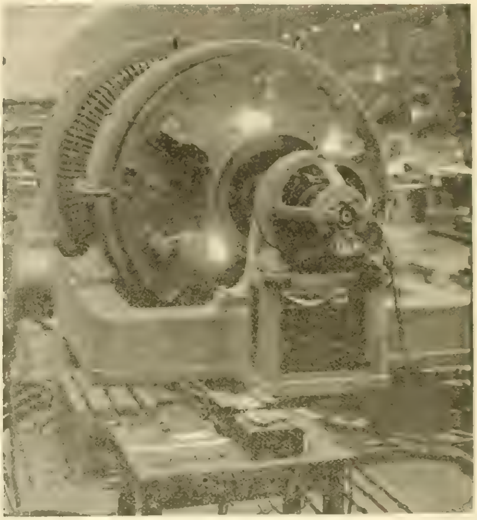


FIG. 9—COMMUTATION UNDER DEAD SHORT CIRCUIT

As shown by oscillogram in Fig. 8.

For the purpose of obtaining engineering data, these and similar tests have been imposed on these generators time and again, until it can be said that on one of these sets, hundreds of short-circuit tests have been made, and in no case has it ever been necessary to replace either a brush or a brush-holder. These machines have successfully withstood the severest short-circuit tests possible and notwithstanding their high-voltage and the acknowledged difficulties of making such machines, they have performed in a manner hitherto considered impossible.

In calling attention to the performance of these generators it is advisable to emphasize the fact that no expense was spared in incorporating every feature favorable to the best performance. Furthermore, it may be stated that, in direct-current machinery, as well as in many other classes of machinery, there are certain ratings, i. e., certain combinations of kilowatts, voltages and speed for which the best performances are possible. Such ratings are the exception rather than the rule and they are looked upon as examples of special merit.

Substation Switching Equipment

Of the Chicago, Milwaukee & St. Paul Railroad

C. M. McL. Moss

THE SWITCHING equipment in the various substations of the Chicago, Milwaukee & St. Paul Railway is not materially different from switching equipment to be found in other railway substations, save that naturally greater precautions have been taken on account of the extreme importance of main line service and the high voltages and large powers involved in this installation.

The various substation buildings are of the same general design, with a high tension room and a motor-generator room separated by a wall. The main switchboard is at the end of the motor-generator room, while the various panels controlling the incoming lines, synchronous motors, transformers for synchronous motors, etc. are located in the wall between the motor-generator room and the high-tension room. The 3000 volt direct-current breakers and the 4400 volt signal switching equipment are mounted in the gallery above the main switch board, as shown for one of the substations in Fig. 1, where the switchboard is at the end of the room, beyond the motor-generator sets with the gallery equipment above the switchboard. To the left is shown the motor panel set in the wall, with the motor rheostat mounted directly above. The panel for control of the auxiliary power, the panel for the control of the high tension side of the transformers supplying power to the synchronous motor, and also the motor panel is shown in Fig. 2.

On the other side of this wall are located the lightning arresters, transformers and oil circuit breakers. These would ordinarily be mounted outdoors, but as it was the desire of the Railway Company to standardize their stations in so far as possible, all this equipment was installed indoors to harmonize with existing equipment in the older stations. Fig. 3 gives some idea of the general appearance of this high-tension room, showing the hand operated oil circuit breakers and disconnecting switches; choke coils are installed in each transformer circuit and are shown at the upper right. At the left, behind the transformers, are shown the lightning arrester tanks, Fig. 4, the horn gaps being mounted on the roof. On the right hand side of Fig. 3 is the rear of a motor panel, with the field switch mounted on the wall above the panel; also the back of the auxiliary panel with the 2300 volt disconnecting switches and short 2300 volt bus-bars above the panel. Fig. 5 shows the condenser type roof bushings and the horn gaps for the lightning arresters.

The typical arrangement of the stations can best be understood by considering a station as a tap on the

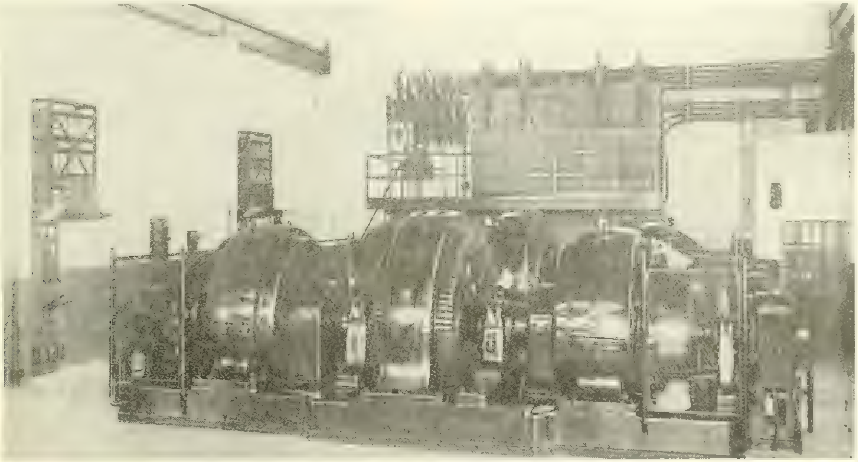


FIG. 1—MOTOR-GENERATOR ROOM

Showing main 3000 volt direct-current switchboard and auxiliary switching equipment.

110 000 volt line, this line being sectionalized at each station, that is to say, the line comes into the station through 110 000 volt, hand-operated, remote-mechanically-controlled oil circuit breakers, and from thence passes to the station bus; leaves the station bus through another similar oil circuit breaker and goes out to the line; lightning arresters being connected to the station bus in each station.

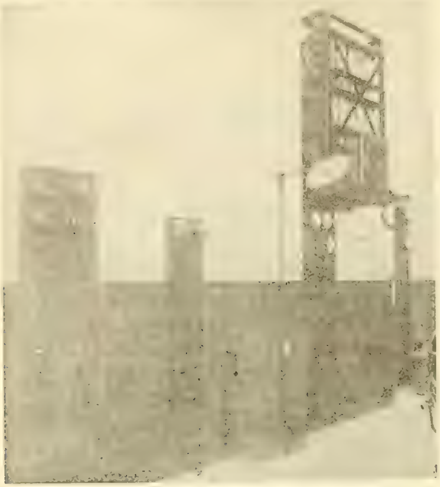


FIG. 2—TRANSFORMER AND MOTOR CONTROL PANELS

For each motor-generator set a three-phase transformer is connected to the station 110 000 volt bus through choke coils, disconnecting switches and oil circuit breaker. Leads pass from the low tension side of this transformer to the starting and running circuit breakers mounted beneath the motor-generator room floor and controlled from the motor panel set in the wall between the motor-generator room and the high tension room. These circuit breakers are mounted in compartments and the arrangement can be seen in Fig. 7, which shows the cell doors removed so that a good idea can be secured of the ruggedness of the switches for this important purpose.

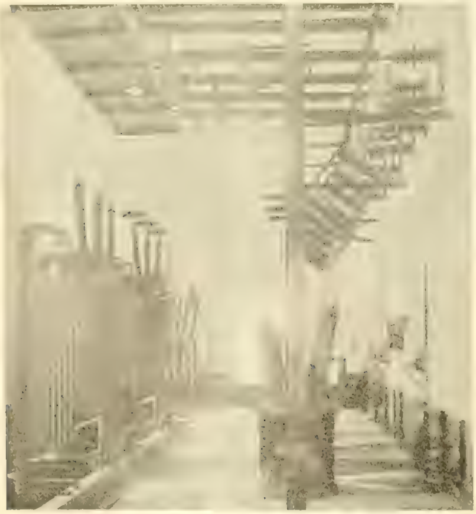


FIG. 3—HIGH-TENSION ROOM

The entire control of the synchronous motor is, in each case, from the synchronous motor panel set in the wall, including the control of the motor field and the field of the exciter for the synchronous motor. From the direct-current end of the motor-generator set ground leads run through a reactance coil to the ground bus, which runs along underneath the motor-generator floor, connecting to each machine and thence to the rail. The positive lead from the motor-generator set and the various field leads and generator exciter leads run over to the main direct-current board, Fig. 6. This board is divided into two parts, one the control and instrument section including all low voltage circuits, and the other the circuit breaker section mounted in the gallery immediately above the panel so as to preclude the possibility of injury to the operator under any normal operation. Great care is taken to secure ample insulation of all apparatus on the switchboard and to this end the ammeters, which necessarily are exposed to the full potential above ground, are mounted on a bakelite disc suitably secured inside of a bakelite case with plate glass front, thus affording the operator convenient vision and absolute safety. Each generator is provided with its own field switch which is mounted behind the

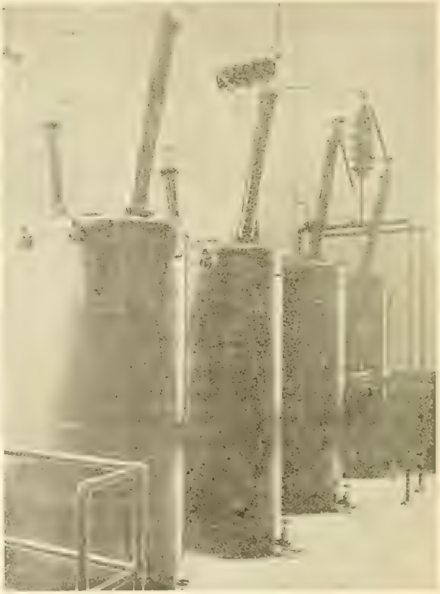


FIG. 4—115 000 VOLT LIGHTNING ARRESTERS

board and operated by a handle in front. In addition there is a solenoid-operated field switch in the circuit from each generator exciter, so that in case of serious trouble the field circuit may be instantly interrupted.

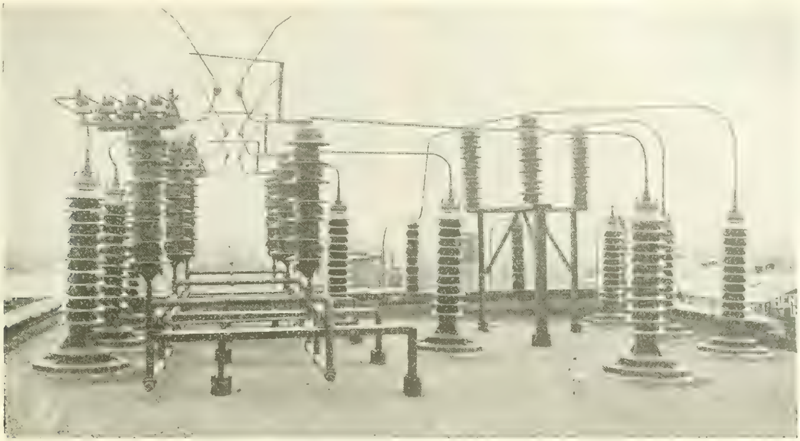


FIG. 5—CONDENSER TYPE ROOF BUSHINGS AND HORN GAPS

Both generator and feeder circuit breakers are provided with an extremely powerful magnetic blowout and large arc chute, and are mechanically operated from levers on the main switchboard. Similarly, the disconnecting switches are remote mechanically controlled and are mounted on the back of the gallery board. Special precaution has been taken in supplying barriers to prevent any possibility of the flash from the 3000 volt circuit breakers spilling over into the disconnecting switches. Bus bars for the 3000 volt circuit are carried on 7500 volt pillar insulators so as to insure great mechanical strength and high degree of insulation.

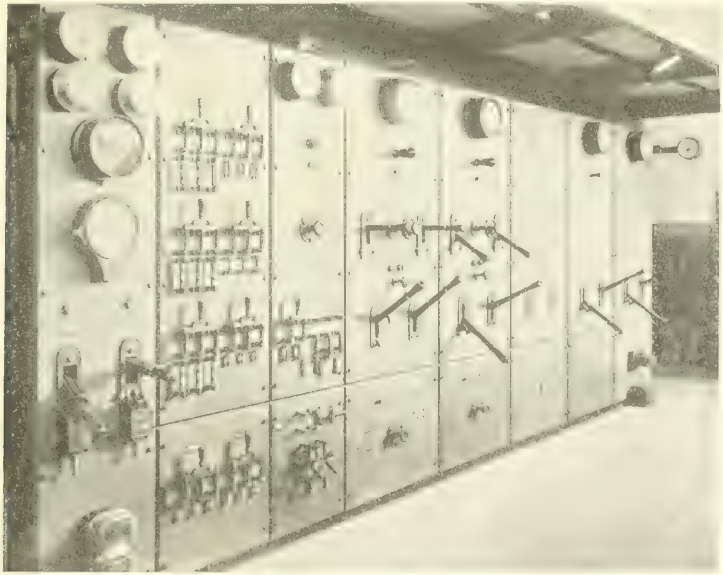


FIG. 6—MAIN DIRECT-CURRENT SWITCHBOARD

Auxiliary power for station light, signals, and other auxiliary purposes is secured by means of transformers which may be connected to either of the motor transformers in operation through oil circuit breakers operated from the auxiliary panel. This 2200 volt line supplies 2200 to 220 volt step-down transformers for operating blower motors, station lights, etc. while a 2200 to 4400 volt single phase transformer supplies 4400 volt single phase power for signals. These auxiliary transformers, together with the generator rheostats and the automatic control panels for the motors driving the blowers for the motor-generator sets are located in the basement, as shown in Fig. 8. There are, of course, innumerable details required by the several functions of the power indicating and limiting equipment which have material bearing on the relay equipment and the functioning of the switching equipment under different conditions. Most of these will be touched on in other articles describing this equipment.

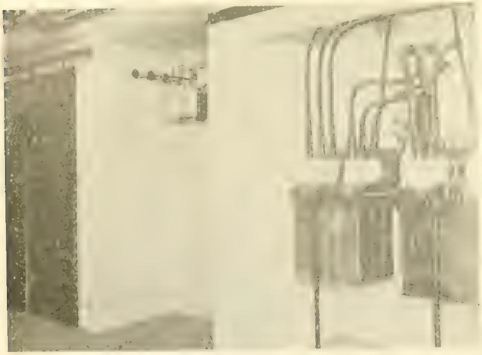
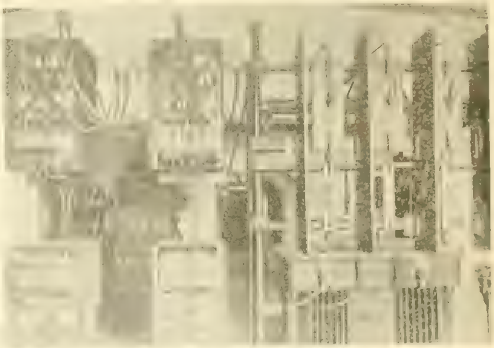


Fig. 7—Motor Control Circuit Breakers



[illegible] and Auxiliary Transformers and Control Panels

The Relation of Flywheel Effect to Hunting in Synchronous Motors

Q. Graham

THE application of synchronous motors to reciprocating loads, such as pumps and compressors, is quite extended. With such loads the torque required during a revolution of the motor is irregular and usually has distinct pulsations which occur one or more times per revolution and which may amount to a large percentage of the total torque. These pulsations in torque cause the rotating part of the motor to pulsate in angular velocity and, under certain conditions, may result in cumulative swinging or hunting of the motor.

It is quite evident that the amount of variation in angular velocity of the rotor, and the angle by which it deviates from its average position, depends upon the shape of the torque curve of the load and upon the mass or inertia of the rotating part. By "average position" is meant the position the rotor would have at any instant, assuming uniform velocity of the same value as the average velocity in the actual case. Large pulsations in the torque curve of the compressor, or other load, mean correspondingly large variations in the angular velocity of the unit. Having the crank effort diagram, which is a curve showing the torque required at each instant during one revolution, and knowing the moment of inertia, or flywheel effect, of the total rotating parts, it is a simple problem in mechanics to calculate the angular displacement of the rotor from its average position, for any particular machine. The displacement is proportional to the pulsation of torque and inversely proportional to the flywheel effect. With heavy flywheels or rotating parts, the periodic displacement can be kept small.

The power taken by the motor varies with the periodic change of the rotor from its average position. As it is always desirable to keep the variation in power small, it would seem that heavy flywheels should be used, and that this would insure small variations. This, unfortunately, is not entirely true because of certain facts which have not yet been considered. Up to this point it has been assumed that the rotor is simply a mass having a certain inertia and that it is acted upon by a pulsating torque. The fact that has not been considered is that a change in the angular position of the rotor of a synchronous motor is accompanied by a change in the torque developed within the motor. It is well known that when a synchronous motor is called upon to exert more torque its rotor drops back a few degrees so that each pole is slightly behind the position it would have occupied had it continued to run at no load. The average speed is still the same, although the rotor has dropped back in phase position. Therefore, when the rotor is caused to shift its phase position periodically, first ahead and then behind its average position, due to an irregular load, the torque developed within the motor is continually changing. There are, then two pulsating torques acting upon the rotating mass; the first is that due to the irregularities of the load outside of the motor and the second is that which is developed within the motor due to the changing phase position of the rotor. The actual variation in the position of the rotor from its average position is due to the combined action of both of these torques. It is not sufficient, therefore, to know the character of the load if the actual amount of angular variation is to be determined; the characteristics of the motor are needed as well.

The simplest solution of the problem of finding the actual angular variation of the rotor requires a somewhat different viewpoint. It has been stated that any change in phase position of the rotor of the motor is accompanied by a change in developed torque. For small changes, the torque is proportional to the angular displacement. Changing the phase position of the rotor may be compared with the compression or elongation of a spiral spring. In each case there is a force which tends to return the body to its normal position and which is proportional to the displacement from the normal position. Thus, if a spring is compressed and then suddenly released, it will vibrate about its mean position for a certain time, each vibration being smaller than the preceding one, and finally come to rest. The time for each complete vibration, or the number of vibrations per second, is a constant value and is dependent upon the physical characteristics of the vibrating body. The same law of vibrating bodies applies in the case of the rotor which is displaced from its normal running position. If a force is applied so as to displace the rotor and then suddenly removed, the rotor oscillates about its average position, and the frequency with which the oscillations occur is constant. The number of oscillations per second is called the natural frequency of oscillation of the motor.

In the case of a motor coupled to a load requiring a pulsating torque, the rotor, which has the property of oscillating according to the laws for vibrating bodies, is subjected to a constantly recurring disturbing force. The frequency with which this force occurs is fixed in any particular case. Usually it is equal to the number of revolutions per second, though it may be some multiple of the number of revolutions per second depending upon the nature of the load. The rotor, which has a fixed natural frequency of oscillation, is acted upon by a disturbing force having a certain fixed frequency. By applying the known laws of the mechanics of vibrating bodies it can be shown that the actual angular displacement of the rotor in such a case depends upon the relative values of the two frequencies—the natural frequency and the frequency of the disturbing force. Expressed mathematically,—

$$D = \frac{d}{1 - \frac{F_1}{F_2}}$$

Where D is the maximum angular displacement of the rotor from its average running position; d is the maximum angular displacement which the rotor would have if it were acted upon by the disturbing force only; F_1 is the frequency of the disturbing force, and F_2 is the natural frequency of oscillation of the motor.

This means that if the value of the disturbing force and the WR^2 of the rotor are known and that, if the displacement of the rotor is worked out, based on these quantities only, the displacement so obtained must be multiplied by a factor depending upon the relation of the natural and forced frequencies to obtain the actual displacement. It can be seen that this factor,

$$\frac{1}{1 - \frac{F_1}{F_2}}$$

becomes large when F_1 and F_2 approach the same value, and that when they are equal the factor becomes infinity. Consequently it is imperative that the natural and the forced frequencies do not coincide, if the displacement is to be kept at a low value. In fact if the two frequencies are within 10 percent of one another, the displacement may be quite large. This is shown by the curve in Fig. 1, which is plotted between the ratio of the two frequencies and the factor which determines the final displacement.

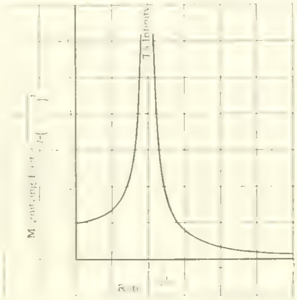


FIG. 1—CONDITIONS WHICH TEND TO PRODUCE MAXIMUM HUNTING

The right hand portion of the curve is really negative, although it is shown as positive in the illustration. Negative values mean that the swinging of the rotor is opposed in phase to the torque pulsation of the load.

It will be well to consider the factors which determine the natural frequency of a motor. It has been stated that the oscillation of the motor about its average position follows the same law as that which applies to vibrating bodies—and to the pendulum as well. In the case of a synchronous motor the expression becomes,—

$F_2 =$ [illegible] $\sqrt{\frac{hp \times freq.}{WR^2 \times \alpha}}$

Where F_2 = the natural frequency in cycles per second; hp = the horse-power of the motor; $freq.$ = the frequency of the line; WR^2 = the flywheel effect of the rotor in lbs.-ft.^{2}; and α = the angular shift of the rotor in electrical degrees corresponding to full load. The latter quantity is the angular shift which the rotor makes from its no load position when running under a steady load. This angle depends upon the design of the machine and must be calculated or measured in any particular case. The calculation of this angle, while theoretically possible, is an approximation at best, so that calculated values of natural frequency must also be accepted as such.

An examination of the expression for natural frequency shows that there are two quantities which may be changed if it should be necessary to change the natural frequency of a motor. It is assumed that the horse-power, speed and line frequency are fixed. Then the only possible changes are in WR^2 and α. The angle may be varied by making changes in the design of the machine, such as making a larger air-gap or using a different number of armature conductors, but this will also affect the other characteristics of the machine. The remaining quantity to be considered is the WR^2. This is usually the one which can most easily be changed, as it is not necessary to make any changes in the motor itself; the required weight can be added in the form of a separate flywheel mounted on the same shaft. In this way the value of the natural frequency may be increased or decreased so as to avoid coincidence with the frequency of the disturbing torque.

For any particular case to be investigated the procedure is as follows. Obtain the torque diagram of the compressor, or other load which the motor drives, and the total WR^2 of the rotating element of the unit. Calculate from these the maximum displacement from the mean position which the rotor would have if it were a simple mass acted upon by the pulsating torque of the load. Multiply this displacement by the magnifying factor,—

[illegible]

to find the actual displacement.

To find the magnifying factor it is first necessary to have the values of the natural and forced frequencies. The expression for natural frequency has been given. The forced frequency is usually the same as the number of revolutions per second, though it may be some multiple of that value. As a matter of fact the torque curve will usually be made up of components of several different frequencies, but the component having the lowest frequency is ordinarily the one which will cause trouble. Each component may be considered as acting independently, but the one which is nearest in value to the natural frequency is the only one that should be given attention.

It will be seen that the flywheel effect or WR^2 is brought into the calculations in two places. A large flywheel effect means a small initial displacement, but at the same time the relation between the natural and forced frequencies may be such as to make the final displacement much higher. It may be more satisfactory in such a case to use a lighter flywheel which, although it allows the initial displacement to be greater, causes the natural frequency to increase to such a value that there is very little magnifying action and that the final displacement is lower.

Various limiting values of periodic angular displacement have been established, but it is rather difficult to decide on any one value which will apply to all cases. A motor operating with a large pulsation in power, due to large periodic displacement, may be entirely satisfactory while operating from a large power system, but, if connected to a smaller system, it may cause such pulsations in the line voltage that other apparatus is affected. Past practice has been to limit the displacement to values of from three to five electrical degrees. These are arbitrary limits which seem to be conservative.

Aside from the effect on the supply system there is the possibility that trouble may arise from such an installation due to the motor dropping out of step. This will occur if the swinging of the rotor carries it through one fourth of a pole pitch or greater.

One important phase of this subject which has been neglected so far is the effect of a damper winding on the motor. When a machine is equipped with dampers and is subjected to variations in angular velocity such as have been considered, there is a torque exerted by the dampers which opposes the changes in velocity. The result is that the actual swing of the rotor is reduced. It may be possible, therefore, to obtain satisfactory operation, even though the foregoing method of analysis shows that the swinging of the rotor will be prohibitive. Calculations of the amount of damping action that can be obtained are usually rather doubtful, but experience has shown that cases of trouble are very rare among machines which are equipped with well designed damper windings. In fact tests have been carried out, on a machine having dampers, with the purpose of producing hunting if possible. The result was that, although the natural frequency was varied by changing the voltage from a point above to a point below the frequency of forced oscillations, no hunting or increase in the periodic pulsation of the motor current could be detected.

The problem that arises in the application of synchronous motors to compressors or similar apparatus is identical with the old problem of parallel operation of engine-driven generators. Experience has proved that these machines are often incapable of operating in parallel when there is a small difference between the natural and forced frequency, but that such trouble may be avoided by equipping the machines with damper windings. Modern practice is to avoid, if possible, coincidence of the two frequencies by the proper selection of flywheel effect and to equip the machines with dampers as an additional assurance of satisfactory operation.

Electrical Characteristics of Transmission Circuits-VI

Wm. Nesbit

FREQUENCY DETERMINATION

Cost of Transformers—Sixty cycle transformers cost approximately 30 to 40 percent less than 25 cycle transformers; or stated another way, 25 cycle transformers cost approximately 40 to 66 percent more than 60 cycle transformers. The saving in first cost may vary between $1.50 and $2.50 per kv-a. in favor of 60 cycles. Assuming that the total kv-a. of transformer capacity connected to a transmission circuit is 2.5 times the kv-a. transmitted over the circuit, the saving in favor of 60 cycle transformers would be $3.75 to $6.25 or an average of $5.00 per kv-a. transmitted. Assuming 20 000 kv-a. to be transmitted, the saving in cost at $5.00 per kv-a. will be $100 000 in favor of 60 cycle transformers. The actual difference in cost will depend upon the type of the transformers, that is, whether water or self-cooled and also upon their average capacity. The difference in cost will be greater for the self-cooled type and for the smaller capacities.

Weight and Space of Transformers—The less weight of 60 cycle transformers makes them easier to handle and they require less space for installation.

Higher Reactance—Inductive reactance at 60 cycles is 2.4 times its value at 25 cycles. This tends to produce poorer voltage regulation of the circuit. Higher reactance has one advantage for the larger systems in that it tends to limit short-circuit currents and thus assists the circuit opening devices to function properly. By virtue of the higher reactance it might be possible in some cases to obtain sufficient reactance in the transformers without the addition of current limiting reactance coils.

Efficiency—The efficiency of 60 cycle transformers is usually 0.25 to 0.50 percent higher than for 25 cycle transformers.

Charging Current—At 25 cycles both the charging current and the reactance are approximately 42 percent of their values for 60 cycles. This tends to give better regulation and usually higher efficiency in transmission. On the other hand, the higher transmission efficiency may be offset by the slightly lower efficiency of 25 cycle transformers. In cases of very long circuits (particularly if the circuits are in duplicate and both in service) or of transmission systems embracing many miles of high tension mains and feeders, the charging currents may be so great as to limit the choice in transmission voltage. On the other hand large charging currents may be permitted, provided under excited synchronous motors are used at various parts of the transmission system for partially neutralizing this charging current and for maintaining constant voltage.

Inductive Disturbances—Lightning, switching and other phenomena cause disturbances on conductors of transmission circuits. The frequency of these disturbances is independent of that impressed on the system. After the removal of the disturbing influence they oscillate with the neutral frequency of the line.

The neutral frequency of the line is far above commercial frequencies but, if the transmission line is long, there may be some odd harmonic present in the fundamental impressed frequency which corresponds with the natural period of the line. This might tend to produce an unstable condition or resonance. This condition is somewhat less likely to occur at 25 cycles.

Summary—Although there are a number of large 25 cycle transmission systems in operation, they were mostly installed before the design of 60 cycle converting apparatus and electric light systems had reached their present state of perfection. Unless it is desirable to parallel with an existing 25 cycle system located in adjoining territory without the introduction of frequency changers, it is now quite general practice to choose the frequency of 60 cycles.*

VOLTAGE DETERMINATION

From a purely economic consideration of the conductors themselves, Kelvin's law for determining the most economical size of conductors would apply. Kelvin's law may be expressed as follows:—

"The most economical section of a conductor is that which makes the annual cost of the I^2R losses equal to the annual interest on the capital cost of the conducting material, plus the necessary annual allowance for depreciation". That is, the economical size of conductor for a given transmission will depend upon the cost of the conducting material and the cost of power wasted in transmission losses. The law of maximum economy may be stated as follows:—"The annual cost of the energy wasted per mile of the transmission circuit added to the annual allowance per mile for depreciation and interest on first cost, shall be a minimum".

Attempts have been made to determine by mathematical expression the most economical transmission voltage, all factors having been taken into account. There are so many diverse factors entering into such a treatment as to make such an expression complicated, difficult and unsatisfactory. There are many points requiring careful investigation, not embraced by Kelvin's law, before the proper transmission voltage can be determined. Some of these points are given below.

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*For a complete discussion of this subject see a paper by D. B. Rushmore before the Schenectady section A. I. E. E., May 17, 1912, on "Frequency" and an article by B. G. Lamme on "The Technical Story of the Frequencies" in the Journal for June, 1918, p. 230.

Cost of Conductors—For a given percentage energy loss in transmission, the cross-section and consequently the weight of conductors required by the lower and medium voltage lines (up to approximately 30 000 volts) to transmit a given block of power varies inversely as the square of the transmission voltage. Thus if this voltage is doubled, the weight of the conductors will be reduced to one fourth with approximately a corresponding reduction in their cost. This saving in conducting material for a given energy loss in transmission becomes less as the higher voltages are reached, becoming increasingly less as voltages go higher. This is for the reason that for the higher voltages at least two other sources of losses, leakage over insulators and the escape of energy through the air between the conductors (known as "corona") appear. In addition to these two losses, the charging current, which increases as the transmission voltage goes higher, may either increase or decrease the current in the circuit depending upon the power-factor of the load current and the relative amount of the leading and lagging components of the current in the circuit. Any change in the current of the circuit will consequently be accompanied by a corresponding change in the I²R loss. In fact, these sources of additional losses may, in some cases of long circuits or extensive systems, materially contribute toward limiting the transmission voltage. The weight of copper conductors, from which their cost may readily be calculated, is given in Table E. As an insurance against breakdown, important lines frequently are built with circuits in duplicate. In such cases the cost of conductors for two circuits should not be overlooked.

TABLE E—WEIGHT OF BARE COPPER CONDUCTORS

B & S NO	AREA IN CIRCULAR MILS	WEIGHT IN POUNDS					
		PER 1000 FEET OF CIRCUIT			PER MILE OF CIRCUIT		
		NUMBER OF CONDUCTORS			NUMBER OF CONDUCTORS		
		ONE	TWO	THREE	ONE	TWO	THREE
	2 000 000	[illegible]	12 360	[illegible]	[illegible]	65 260	[illegible]
	1 900 000	5 870	11 740	17 610	[illegible]	[illegible]	[illegible]
	1 800 000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	1 700 000	5 250	10 500	[illegible]	27 720	[illegible]	[illegible]
	1 600 000	4 940	9 880	[illegible]	[illegible]	52 166	78 249
	1 500 000	4 630	9 260	[illegible]	[illegible]	[illegible]	[illegible]
	1 400 000	4 320	8 640	12 960	[illegible]	[illegible]	[illegible]
	1 300 000	4 010	8 020	12 030	[illegible]	[illegible]	63 519
	1 200 000	3 710	7 420	11 130	[illegible]	[illegible]	[illegible]
	1 100 000	3 400	6 800	10 200	[illegible]	35 904	[illegible]
	1 000 000	3 090	6 180	9 270	[illegible]	[illegible]	[illegible]
	950 000	2 930	5 860	[illegible]	[illegible]	[illegible]	[illegible]
	900 000	2 780	5 560	8 340	[illegible]	29 356	[illegible]
	850 000	2 620	5 240	7 860	[illegible]	[illegible]	[illegible]
	800 000	2 470	4 940	7 410	[illegible]	[illegible]	[illegible]
	750 000	2 320	4 640	6 960	[illegible]	[illegible]	[illegible]
	700 000	2 160	4 320	6 480	[illegible]	[illegible]	[illegible]
	650 000	2 010	4 020	[illegible]	[illegible]	[illegible]	[illegible]
	600 000	1 850	[illegible]	[illegible]	[illegible]	19 536	[illegible]
	550 000	1 700	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	500 000	[illegible]	[illegible]	[illegible]	8 131	[illegible]	[illegible]
	450 000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	400 000	[illegible]	[illegible]	[illegible]	6 547	[illegible]	[illegible]
	350 000	[illegible]	[illegible]	[illegible]	5 702	[illegible]	[illegible]
	300 000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	250 000	772	[illegible]	[illegible]	[illegible]	8 152	[illegible]
0000	212 000	653	1 306	[illegible]	[illegible]	[illegible]	10 344
000	168 000	[illegible]	1 036	[illegible]	[illegible]	[illegible]	[illegible]
00	133 000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0	106 000	[illegible]	[illegible]	[illegible]	[illegible]	3 442	5 163
1	83 700	258	[illegible]	[illegible]	[illegible]	[illegible]	4 086
2	66 400	[illegible]	[illegible]	[illegible]	[illegible]	2 164	[illegible]
3	52 600	163	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	41 700	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2 043
5	33 100	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1 617
6	26 300	81	[illegible]	[illegible]	[illegible]	[illegible]	1 284
7	20 800	64	128	[illegible]	[illegible]	[illegible]	[illegible]
8	16 500	51	[illegible]	[illegible]	[illegible]	538	[illegible]

Table E contains the weights of bare stranded copper cables per 1000 feet of circuit, also per mile of circuit. For the purpose of facilitating rapid calculation for any given case, the weights are given corresponding to one, two and three conductors for these two lengths of circuit.

Reduced Electric Surges—The better insulation necessitated by higher transmission voltages tends to make the circuit more secure against ordinary disturbances. Also the smaller currents resulting with the higher voltages cause less disturbance in the circuit in the case of grounds, short-circuits, switchings, lightning and other disturbances.

Less Reactance Volts Drop—Since the current corresponding to higher transmission voltages goes down as the voltage goes up, the voltage necessary to overcome the reactance of the circuit will be less, and the percentage reactance volts much less for higher voltages. Thus, if the transmission voltage is doubled, the current will be halved and for the same spacing of conductors the reactance volts drop will be one half, resulting in one fourth the percentage of the reactance-volts drop.

TABLE F—PRESENT RELATIVE COSTS OF HIGH TENSION APPARATUS

Expressed in Percent (6600 Volt Costs Taken as 100%)

	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Transformers	100	102	104	106	108	115	125	150	175	200	225
Switches	100	100	100	100	100	110	115	155	255	420	
Electrolytic Arresters	100	151	160	105	205	320	430	640	1600	1000	2400
Insulators	100	135	185	365	430	650	1250	3500	5500	6500	7700

Cost of Transformers—If the transmission voltage exceeds 13 200 volts, banks of step-up transformers will be required of sufficient capacity to transform all of the kv-a. to be transmitted. A still greater capacity of step down transformers will be required to reduce the voltage to that suitable for operating motors and lights. In some cases two reductions from the transmission circuit voltage may be required, the first usually reducing to 22 000, 11 000 or 6600 volts for general distribution and the second reducing from the general distribution voltage to the proper voltage for motors and lights. The net result is that the total capacity in transformers connected to a transmission system employing both step up and step down transformers may vary from a minimum of two to a maximum of about four times the kv-a. transmitted over the high-tension circuits. The average condition we will assume as 2.5 times the kv-a. to be transmitted.

The cost of power transformers at the present time for 66 000 volts service will vary between $1.25 to $3.00 for 60 cycle and $2 to $5 per kv-a. for 25 cycle service, depending upon their type and capacity. The total cost per kv-a. of transformers on a system would therefore be represented by approximately 2.5 times the above costs. The present relative costs of transformers for different voltages are given in Table F. For instance if the transmission voltage is increased from 33 000 to 66 000 volts the transformers will cost in the neighborhood of 150 ÷ 115 or 31 percent more than they would cost for 33 000 volts. Knowing the amount of power to be transmitted, an approximate estimate may be made as to the additional cost of the necessary transformers for a higher voltage.

Cost of Insulators—Table F values indicate a wide difference in the cost of insulators for the higher voltages; thus the increased cost of 66 000 volt insulators above the cost of 33 000 volt insulators is stated as 3500 ÷ 650 or 540 percent.

Cost of Other Apparatus—The cost of lightning arresters, high-tension circuit breakers and general insulation increase with the voltage. The increased cost of these items, however, may not have sufficient weight to materially influence the selection of the transmission voltage.

Cost of Buildings—Lower voltage transformers, switching equipment and lightning arresters require less space for insulation. If this apparatus is to be placed indoors, the cost of necessary buildings may be less. The amount of real estate required may also be less in case of the lower voltage.

Relative Cost Values—Table F contains relative cost values for different transmission voltages. They indicate approximately the variation, at the present time, in cost of the principal material which is affected by a change in transmission voltage. Cost values are very unstable at present but the table will serve in a general way to indicate comparative costs.

Efficiency—The efficiency of transformers will be slightly higher for the lower voltages.

Small Customers—The furnishing of power to small customers at points along the transmission circuits should receive careful consideration. The cost of switching apparatus, lightning arresters and transformers required to permit service being given to such customers will be less for the lower voltage.

Charging Current—The amount of current required to charge the transmission circuits varies approximately as the transmission voltage. Therefore the charging current, expressed in kv-a. varies approximately as the square of the voltage. Thus the charging current required for a 33 000 volt circuit is approximately one half and the charging kv-a. one fourth that of a 66 000 volt circuit.

TABLE G—FORM OF TABULATION FOR DETERMINING VOLTAGES AND CONDUCTORS

BASED ON THE TRANSMISSION OF 10 000 KV-A FOR TEN MILES AT 80 PERCENT POWER-FACTOR LAGGING 60 CYCLES, THREE PHASE

VOLTAGE		CONDUCTORS								[illegible] FULL LOAD			[illegible]						ANNUAL OPERATING COST			
						TOTAL I²R LOSS 10 000 KV-A		TOTAL I²R LOSS 2500 KV-A														
BETWEEN CONDUCTORS	TO NEUTRAL	AMPERES FOR 10 000 KVA	B & S OR CIRCULAR MILS	TOTAL WEIGHT IN POUNDS	RESISTANCE OHMS	KW FOR 10 HRS	LOSS IN %	KW FOR 14 HRS	TOTAL LOSS PER YEAR IN KW—HOURS	RESISTANCE IR IN %	REACTANCE IX IN %	VOLTS DROP IN %	CONDUCTORS AT 25 CTS PER POUND	TRANSFORMERS 25, 000 KVA	HIGH TENSION SWITCHES	LIGHTNING ARRESTERS	INSULATORS	TOTAL	INTEREST ON FIRST COST AT 6%	DEPRECIATION ON FIRST COST AT 10%	I²R LOSSES AT 1 CT PER KW—HOUR	TOTAL
11 000	6 352	525	500 000	243 480	[illegible]	[illegible]	5.3	27	[illegible]	4.3	21.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	$40 882	[illegible]	[illegible]	[illegible]	[illegible]
			300 000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7.2	22.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	400	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			#000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	24.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
22 000	12 702	262	300 000	[illegible]	[illegible]	413	5.0	25	[illegible]	4.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	400	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			#000	[illegible]	[illegible]	720	9.0	45	[illegible]	7.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	200	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			#0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	200	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
33 000	19 053	175	#00	[illegible]	[illegible]	406	[illegible]	25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	33 002
			#2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			#4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
44 000	25 404	131	#2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			#5	[illegible]	[illegible]	[illegible]	[illegible]	59	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Summary—In deciding upon the transmission voltage, careful and full consideration should be given to the present (or probable future) voltage of any neighboring or adjacent systems. There is an increasing tendency to combine generating and transmission systems for purposes of economy, and insurance against breakdown in service. If a possible future consolidation is not kept in mind when selecting the transmission voltage, a voltage may be decided upon which would render it impossible to parallel with a neighboring system, except through connecting transformers. In this case the transformers of the two systems would probably not be interchangeable for service on either system.

If the contemplated transmission system is remote from any existing system, a study of the initial and operating costs should be made corresponding to various sizes of conductors and to various assumed transmission voltages. A suggested tabulation for such comparisons is shown in Table G. In this table, it is assumed that 10 000 kv-a. (8000 kw at 80 percent power-factor lagging), is to be transmitted a distance of ten miles at 60 cycles, three-phase for ten hours, followed by

2500 kv-a. (2000 kw at 80 percent power-factor lagging) for 14 hours. Delta spacing is assumed of three feet for the lower two and four feet for the higher two voltages. Raising and lowering transformers will be required of an assumed total capacity of 2.5 × 10 000 or 25 000 kv-a. Conductors of hard drawn stranded copper are employed, the resistance of the conductors being taken at a temperature of 25 degrees C. from Table II. (July, 1919).

The cost of the pole or tower line, the right of way, buildings and real estate for buildings is not included in this tabulation. Neither is the difference in transformer efficiencies taken into account. The difference in these items will not be sufficient in this case greatly to influence the choice of the transmission voltage, because all of the voltages compared are relatively low. Because of the large amount of power to be transmitted a comparatively short distance, the approximate rule of 1000 volts per mile for short lines does not hold true for this problem.

Assuming for the sake of argument that the price values given in this form of tabulation are approximately correct for this problem and that there are no neighboring transmission systems, then the problem reduces to cost economics.

Since both the first and operating costs in Table G are higher for 16 500 volts than they are for 22 000 volts, it is evident that 16 500 volts is economically too low a voltage.

In the consideration of 22 000 volts it will be seen that, of the three sizes of conductors, the largest size (300 000 circ. mil.) will be the cheaper in the end. Thus, if No. 000 were selected, the first cost would be $16 159 less than for 30 000 circ. mil conductors, but the operating cost (due to greater loss in transmission) will be approximately $10 000 a year more. For a similar reason No. 0 conductors will be disqualified.

In the consideration of 33 000 volts, No. 00 conductors will be the choice and in the consideration of 44 000 volts, No. 2 conductors will be the choice. The choice then comes down to the following:—

Voltage Transmission	Conductors	Total Cost First	Annual Operating Cost
22 000	300 000 circ. mils	$118 420	$34 034
33 000	No. 00	105 655	33 002
44 000	No. 2	107 727	35 288

It will thus be seen that a voltage of 33 000 volts and No. 00 conductors are the most economical of those tabulated. The transmission loss will be 5.1 percent, the reactance 6.5 percent and the voltage drop seven percent at full load. The value assigned as the cost per kw-hour for power lost in transmission will obviously have great influence in determining the proper economic size of conductors for any given transmission voltage. The cost of the copper will have a relatively greater importance on longer lines. As a matter of fact, a larger size than any of the conductors listed in Table G would be still more economical, under the conditions given. There have been numerous mistakes made in under-estimating the ultimate demand for electrical power and consequently adopting too low a transmission voltage. When in doubt the higher voltage will, in the course of time, most likely justify its adoption by reason of future growth not apparent at the time the choice is made.

The design and construction of transformers, circuit breakers, lightning arresters, etc. for a multiplicity of high-tension voltages is expensive. The manufacturers of such apparatus are endeavoring to standardize transmission voltages for the purpose of minimizing the number of designs of high-tension apparatus. This point could with mutual profit be taken up with the manufacturers before any particular voltage is decided upon.

TABLE H—COMMON TRANSMISSION VOLTAGES

Length of Line	Voltages
1 to 3 miles	550 or 2200 volts
3 to 5 miles	2200 or 6600 volts
5 to 10 miles	6600 or 13 200 volts
10 to 15 miles	13 200 or 22 000 volts
15 to 20 miles	22 000 or 33 000 volts
20 to 30 miles	33 000 or 44 000 volts
30 to 50 miles	44 000 or 66 000 volts
50 to 75 miles	66 000 or 88 000 volts
75 to 100 miles	88 000 or 110 000 volts
100 to 150 miles	110 000 or 132 000 volts
150 to 250 miles	132 000 or 154 000 volts
250 to 350 miles	154 000 or 220 000 volts

The amount and cost of power to be transmitted is a very important factor in determining the economic transmission voltage. For average conditions isolated from existing transmission lines the voltages shown in Table H have been quite generally used. For exceptional cases, exceptional values will be used. For example if 40 000 kv-a. is to be transmitted 20 miles, 66 000 volts or higher might be used. On the other hand if a very small amount of power is to be transmitted, lower voltages would probably be selected.

At the present time the prospects seem bright for the standardization of the following "normal" system voltages.

44 000
66 000
88 000
110 000
132 000
154 000
*187 000
220 000

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*The use of 187 000 volts is likely to occur only in case it is found necessary to have a voltage between 154 000 and 220 000 volts.

Switchboard Meter Connections

For Alternating-Current Circuits

J. C. GROUP

MAKING connections to switchboard meters involves an understanding of the physical and electrical characteristics of the particular circuit to be considered, the results to be obtained from the use of the electrical instruments, and the detail requirements for correct operation of the instruments themselves. Even with this knowledge at hand, the problem of making correct connections is often so complex that it requires special treatment. The use of vector diagrams is most helpful in solving such problems, and in many cases is the only direct means by which a correct solution can be obtained. In the discussions which follow, there will be presented an explanation of the vector diagram and its use with the combinations of meters that are most common in present-day practice, and also some of the special applications which frequently occur. In all diagrams, meters are shown as viewed from the rear, because all connections are made at the back of switchboards.

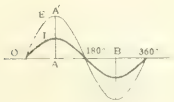

FIG. 1—WAVE FORM OF AN ALTERNATING VOLTAGE AND CURRENT

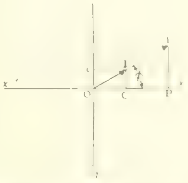

FIG. 2—[illegible] OF AN ALTERNATING VOLTAGE AND CURRENT

SELECTION OF POSITIVE DIRECTIONS IN AN ALTERNATING-CURRENT CIRCUIT

In an alternating-current circuit, the voltage is in one direction during the first half of each cycle and in the opposite direction during the rest of the cycle, and in response to that voltage the current flow is also in one direction for the first half and in the opposite direction for the rest of the cycle. Since the voltage and current are reversed at corresponding times, the reaction between the voltage coil and the current coil of a meter is the same throughout the entire cycle, and for that reason either direction of voltage and current may be considered positive so long as the assumption is consistent for both voltage and current. For simplicity in making connections, it is common usage to consider the direction from the power to the load as positive and, when instrument transformers are used, to consider the currents in the meter circuits to be in the same direction as if the transformer were omitted and the secondary circuit connected into the primary circuit in its place.

REPRESENTATION OF ALTERNATING VOLTAGES AND CURRENTS

The voltage in an alternating-current circuit may be represented by a wave form, called a sine wave, for the reason that modern alternators are designed to give approximately this wave form. Curve *E* in Fig. 1 shows such a wave form where horizontal distances represent electrical degrees and vertical distances instantaneous values of voltage. An electrical degree is 1/360th part of a period or cycle, or 360 degrees on the horizontal reference line compose one cycle. *AA′* represents the maximum value of the voltage when in one direction and *BB′* in the opposite direction; or the values above the reference line may be considered positive and those below the line negative. Since the wave form of current is always similar to that of the voltage, *I* represents the current (in phase with the voltage) that would flow in a circuit with the voltage *E* impressed on it. Such curves give a very definite idea of the conditions in the circuit at each instant, but they are very difficult to draw accurately and cannot be used easily in analyzing circuits for determining how to connect meters correctly.

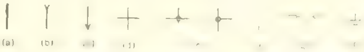

FIG. 3—[illegible] IN CONNECTION DIAGRAMS

a—Main line power conductor.
[illegible]
i—Condenser, surrounding power conductor.
j—Current transformer.

The most convenient representation is obtained by the vector diagram. A simple vector diagram is shown in Fig. 2 where *XX′* and *YY′* are reference axes perpendicular to each other and intersecting at the point *O*. The vector *OE*, the length of which represents the maximum value of the voltage, is drawn from the point *O* making an angle ϕ with the axis *XX′*, where ϕ is the number of electrical degrees from the beginning of the cycle to where it is desired to show the conditions in the circuit. In vector diagrams, electrical degrees are equal to degrees in angular measure and therefore 360 degrees, or one revolution of the vector *OE* about the point *O* at uniform angular velocity, represents a complete cycle. Where there are a number of vectors displaced from one another by given angles, all the vectors are considered as revolving at the same angular velocity, their lengths and angular displacements remaining constant. It is standard practice to assume counter-clockwise direction of rotation for all vector diagrams.* The line *EB* drawn perpendicular to *XX'* in Fig. 2, represents the instantaneous value of the voltage, since it is equal to *OE* sine ϕ, which is an equation of the sine wave. Likewise the vector *OI* and the line *IC* represent the maximum and the instantaneous values of a current in phase with the voltage.

It is apparent from Fig. 2 that, when the vectors *OE* and *OI* are projected on the vertical axis, the projections *Ob* and *Oc* represent instantaneous values of the voltage and current, since they are equal respectively to *BE* and *CI*. This method is often the most convenient to employ where instantaneous values are to be considered. However, for the present purpose, instantaneous values are of little importance, since it is either the maximum or the effective values of the various voltages and currents, and the phase angles between them, that must be known in order to connect electrical instruments so they will operate as desired.

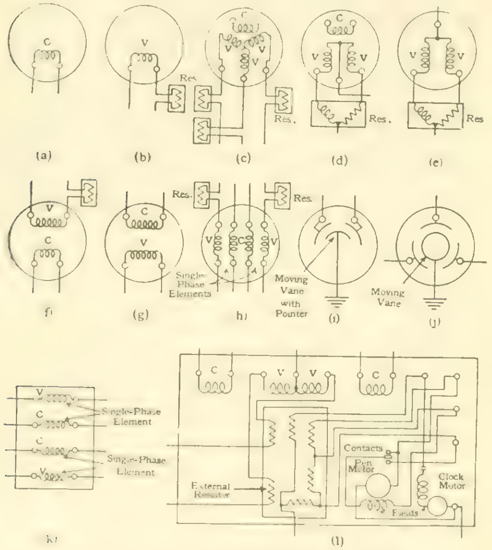

FIG. 4—INTERNAL CONNECTIONS OF METERS

The vector diagram may be constructed to represent the effective values of voltages and currents as well as the maximum values, because the ratio of the effective value to the maximum value is a constant, namely, $0.5\sqrt{2}$. For the reason that the effective values are used for ordinary alternating-current calculations, in the discussions to follow, all mention of voltage and current will have reference to the effective values.

In most cases it is not necessary to construct reference axes such as XX' and YY' in Fig. 2, for some vector, preferably a voltage vector, may be used as a reference line and all other vectors may be drawn at their respective angles to this reference vector. In referring to vectors, only the letters or figures placed at the arrow points need be mentioned for all vectors are shown radiating from the point which is the center of rotation for the figure. For representing the normal conditions in a circuit, it is best to construct the vector diagram on the basis of 100 percent power-factor, and for balanced load in case of polyphase circuits.

CONVENTIONAL REPRESENTATIONS

A set of conventional representations is shown in Fig. 3 that will be used in making all the wiring diagrams for the circuits to be considered. In Fig. 4 is shown a schematic representation of the internal connections of the different meters. The following brief notes of explanation will assist in understanding their use in the wiring diagrams:—

a—Ammeter.

b—Voltmeter with external resistor.

c—Three-phase power-factor or reactive factor meter with external resistors in series with the voltage coils.

d—Single-phase power-factor or reactive factor meter with an external resistor, which consists of an inductance and a non-inductive resistance connected in series with the two voltage coils for a split-phase arrangement to produce a rotating field.

e—Frequency meter with an external resistor which consists of an inductance and a non-inductive resistance connected in series with the two voltage coils for a split-phase arrangement to produce a rotating field.

f—Single-phase wattmeter with external resistor in series with the voltage coil.

g—Single-phase watthour meter.

h—Polyphase wattmeter with external resistors in series with the voltage coils. This instrument consists of two single-phase elements actuating one pointer on a scale which reads the total power measured by the two elements.

i—Single-phase ground detector which indicates a ground on either line of a single-phase circuit by a pointer attached to a moving vane. The moving vane swings away from the fixed vane connected to the line on which the ground occurs.

j—Three-phase ground detector which indicates a ground on any phase by a movable indicating vane which swings away from the fixed vane connected to the line on which the ground occurs.

k—Polyphase watthour meter which consists of two single-phase elements operating on one registering mechanism which registers the total power measured by the two elements.

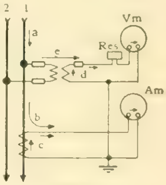

Fig. 5

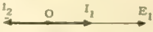

Fig. 6

FIG. 5—SINGLE-PHASE, TWO-WIRE CIRCUIT WITH VOLTAGE AND CURRENT TRANSFORMERS

FIG. 6—VECTOR DIAGRAM FOR SINGLE-PHASE, TWO-WIRE CIRCUIT

l—Polyphase graphic wattmeter of the Kelvin Balance type. This instrument consists of two single-phase elements actuating one pointer and graphic recording mechanism. The paper for the praphic record is moved by a clock which is wound at regular intervals by a motor, and the pen is also moved by a motor which is controlled, through a pair of contacts, by the power measuring elements. The power is supplied to the clock motor and pen motor from an auxiliary control circuit. The control circuits for all the graphic meters, shown in the wiring diagrams which follow, are the same. The external resistor contains the necessary resistance for use in connection with the control circuits and, with the exception of the graphic frequency meter, contains the resistances used in series with the voltage coils of the measuring elements. For the graphic frequency meter the inductance and non-inductive resistance for the split-phase arrangement are mounted in a box separate from the control resistor. The polyphase graphic wattmeter is used on single-phase circuits by connecting the current coils in series and the voltage coils in parallel. Ammeters, voltmeters and other instruments of this type are essentially similar, except for the windings and connections of the balance coils.

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*See paragraph 20, Standardization Rules of the A. I. E. E.

SINGLE-PHASE CIRCUITS

For a single-phase two-wire circuit as shown in Fig. 5, the direction of power transmission is indicated by the arrow points on the line leads. This is to be taken as the positive direction in the circuit and then when the voltage is in the direction from line 1 to line *2*, the current that flows in line *1* is in a positive direction, as indicated by the arrow *a*. A vector diagram for this circuit may be constructed as shown in Fig. 6 where vector $E_{1\,2}$ represents the voltage when in the direction *1* to *2* and I_1 represents the current in line *1*. The vector I_2, equal in length to and 180° out of phase with I_1, represents the current in a positive direction in line *2*. Since for the single-phase two-wire circuit I_2 is the same current as I_1 except in the opposite direction with reference to the positive direction in the circuit, I_2 may be considered as being equal to $-I_1$.

INSTRUMENT TRANSFORMERS

The leads of voltage and current transformers are brought out and marked so that the polarity is as shown in Fig. 5. For the current transformer, the direction of the secondary current through the ammeter is as shown by the small arrows *c* and is the same as would be the direction of the primary current if the transformer were not used and the line lead were looped through the ammeter as indicated by the arrow *b*. The conditions are similar for the voltage transformer, that is when the primary voltage is from *1* to *2*, the direction of the secondary voltage impressed on the voltmeter is as indicated by the small arrows *d* and is the same as it would be if the transformer were not there and the taps from the line leads were taken directly to the meter as indicated by the arrow *e*.

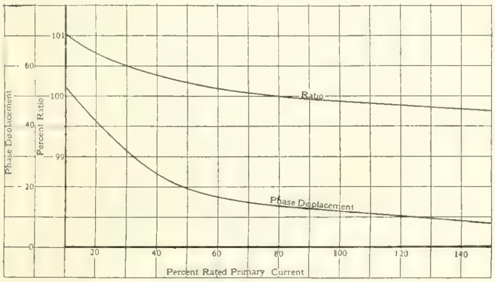


FIG. 7—CHARACTERISTIC CURVES OF A HIGH GRADE CURRENT TRANSFORMER

For determining from a vector diagram the phase angles between secondary voltages and currents for meter connections, it is not necessary to construct a separate set of vectors to represent these secondary values for, neglecting phase displacement in instrument transformers, the vectors which represent the primary values may be considered to represent also the corresponding values on the secondary side of the transformers. When the correct selection of the positive direction has been made in the secondary circuits, it is sufficient for the purposes here to consider the secondary voltages and currents in phase with the corresponding primary voltages and currents and simple multiples of them as determined by the ratio of transformation of the instrument transformers. For the secondary circuits it is customary to consider the direction from the transformers to the instruments as positive.

Fig. 7 shows typical ratio and phase displacement curves for a good current transformer. The ratio is shown to be correct at eighty percent of rated primary current, which in general practice is about the percent of rated primary current at which a current transformer operates for the greater part of the time. Within the range from 60 to 120 percent of rated primary current, the error in ratio is very small, being a little over one-tenth of one percent, and the angle of phase displacement is so small that, for all practical purposes it is negligible. The better grades of current transformers have a capacity of fifty volt-amperes and are compensated for a load of from twenty-five to forty volt-amperes, but some of the cheaper grades have much smaller capacities than this. For any specific case the manufacturer's recommendations should be followed as to the load of instrument coils that can be connected to a given current transformer to secure a satisfactory degree of accuracy. Current transformers which are to be used only for actuating trip coils, etc. are sometimes made up very cheaply, and while satisfactory for the purpose for which they are intended, such transformers should not be used for meter circuits.

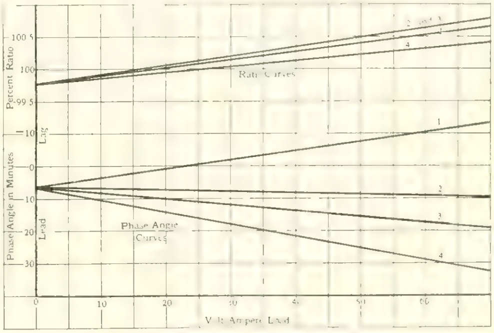


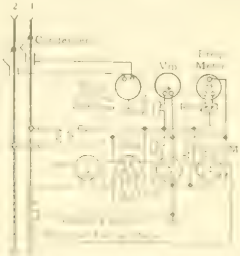
FIG 8—CHARACTERISTIC CURVES OF A HIGH GRADE VOLTAGE TRANSFORMER

1—For 100 percent power-factor.
2—For 80 percent power-factor.
3—For 60 percent power-factor.
4—For 15 percent power-factor.

Fig. 8 shows typical ratio and phase displacement curves for a good voltage transformer suitable for operating meters and other apparatus having voltage coils used on switchboards. The voltage transformers usually have a capacity of 200 volt-amperes and are compensated for a load of 15 to 30 volt-amperes, but they can be compensated by the manufacturer for any load within their capacity. Within the range from 15 to 30 volt-amperes, the ratio is very nearly correct, the maximum variation for any curve being about two-tenths of one percent. When compensated for any other load the ratio would be correspondingly accurate. Automatic generator voltage regulators require voltage transformers with capacities as high as 500 volt-amperes, and in such cases separate transformers should be used with them, that is, meters should not be operated from the same transformers. For any specific case, the manufacturer's recommendations should be followed as to the load of instrument coils that can be connected to a given voltage transformer to secure a satisfactory degree of accuracy.

In Table I is given the energy in volt-amperes and watts required to operate the different instrument and apparatus coils which are commonly connected to current and voltage transformers in switchboard practice. The values given in the table are somewhat general for the various types of apparatus. However, for any specific case, the values recommended by the manufacturer of the particular instrument or piece of apparatus should be used in making final calculations.

It is evident that when a number of instruments are to be used on a circuit, it is not necessary to provide separate voltage and current transformers for each instrument, unless very accurate results are required. The number of instruments that can be operated from the same transformers depends on the volt-amperes required to operate the instruments, the capacity in volt-amperes of the transformers, and the accuracy desired. If the volt-amperes required to operate the instruments greatly exceeds the capacity of the transformers, the ratio of transformation becomes impaired and the results obtained are necessarily inaccurate. Combinations such as shown in the following figures usually may be made with the ordinary transformers, and in many cases more instruments could be used without materially impairing the accuracy.

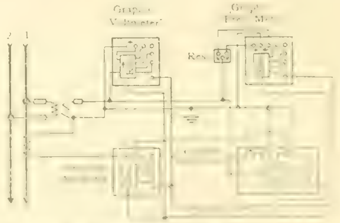


[illegible] INDICATING [illegible]

INSTRUMENTS ON SINGLE-PHASE TWO-WIRE CIRCUITS

A group of meters is shown in Fig. 9 that is suitable for a single-phase two-wire generator or feeder circuit, or for station bus-bars. Connections are shown for using instrument transformers because in most cases the voltages and currents are such that they are necessary. The voltage transformer supplies the voltage for the voltmeter, frequency meter, power-factor or reactive factor meter, indicating wattmeter, and the watthour meter. The watthour meter is connected to a separate current transformer as would be necessary for light load accuracy. The ammeter, power-factor, or reactive factor meter, and the indicating wattmeter are all connected to the other current transformer. One side of the instrument transformers is grounded, which is customary practice for switchboard wiring. If instrument transformers are not used, the ground connection should not be made, as it would ground the power lines. The static ground detector is connected to each line lead through a condenser, a condenser being used for each lead, so that it will indicate when a ground occurs and also which line becomes grounded.

In the conventions used to represent the electrical instruments, no attempt is made to show the internal connections, which have all been given in Fig. 4, but the direction that the current takes through the coils from one terminal to another is indicated by the small arrows. These arrows point in the positive direction of the secondary circuits for the assumed condition where the line voltage is from *1* to *2* and the current in line *1* is in a positive direction as indicated by the arrow points on the line leads, which show the direction of power transmission. For the instruments having both voltage and current coils, the small arrows represent the relative direction of currents through these coils to produce correct operation. If the connections were so made that the currents would flow in the opposite direction through all the voltage and current coils of an instrument so that all the small arrows would point in the reverse direction, the instruments would also operate correctly.

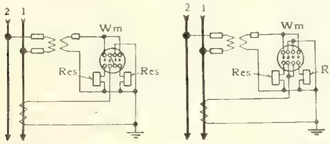


[illegible] ON A SINGLE-PHASE, TWO-WIRE CIRCUIT

The vector diagram in Fig. 6 will apply for all the single-phase circuits shown, since the same assumptions regarding positive directions are made for each figure. The connections for instruments on a single-phase circuit are so easily made that the vector diagram is of little help aside from representing the conditions in the circuit.

In Fig. 10 are shown the connections for a number of graphic recording meters for a single-phase two-wire circuit. It would seldom occur in practice that so many graphic records would be desired for one circuit, but the meters are shown in one group to illustrate the method of connection. In addition to the secondary circuits of the instrument transformers, an auxiliary control circuit is required to operate the mechanism within these meters. The positive direction of current in the current and voltage coils is indicated, but no attempt is made to indicate the auxiliary control circuits, for these are explained in Fig. 4 (*l*).

It is sometimes convenient in an emergency to use a polyphase wattmeter for measuring power on a single-phase circuit. The polyphase wattmeter consists of two single-phase wattmeter elements acting on the same pointer or register. Two possible connections are shown in Figs. 11 and 12. In Fig. 11 the current coils are connected in series and the voltage coils in parallel. The reading obtained with this connection is twice the actual power, but is the most accurate indication because both elements of the meter will be operating on the values of current and voltage for which they were designed. In Fig. 12 the current coils are in parallel and the voltage coils are in parallel. With this arrangement the meter registers actual power, but the readings may not be as accurate as for the connection in Fig. 11 because of the low value of current in the current coils due to the parallel connection. Even if the current coils have exactly the same impedance, so that the current divides equally, at full load the current which flows through the current coil of each element is only one-half of that for which the meter is designed, and for smaller loads is correspondingly less.



FIGS. 11 AND 12—CONNECTIONS FOR A POLYPHASE WATTMETER ON A SINGLE-PHASE CIRCUIT

Fig. 11—With the current coils connected in series the indication is twice the actual power.

Fig. 12—With the current coils connected in parallel the indication is the actual power.

SINGLE-PHASE THREE-WIRE CIRCUITS

It is often advantageous, especially for distribution circuits, to use a single-phase three-wire system such as shown in Fig. 13. The voltage from each of the main line leads to the neutral lead is that desired for distribution, the voltage between the two outside or main leads being double the distribution voltage. The load is connected between each of the outside leads and the neutral so that there is as near an equal load on both sides as possible. It is evident that when the load is evenly divided, there will not be any current flowing in the neutral line. The only current that the neutral line ever does carry is that due to the difference in load on the two sides.

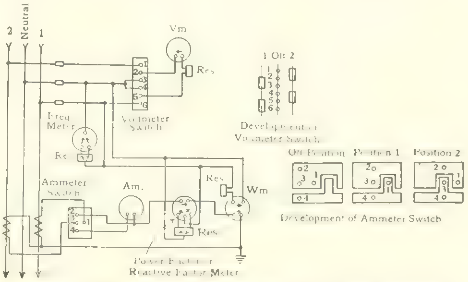


FIG. 13—TYPICAL GROUP OF METERS ON A SINGLE-PHASE, THREE-WIRE CIRCUIT

Using instrument switches for reading the voltage and current in each side of the circuit with a single voltmeter and ammeter.

In Fig. 13 connections are shown for a group of meters which is suitable for a single-phase three-wire circuit. Voltage transformers are not shown, for usually the voltage in such circuits is low enough that they are not necessary. In this case the voltage circuits of the meters are not grounded. In many distributions circuits, the neutral line is grounded, and when this is done the voltage circuit of the meters is grounded. The positive direction of voltage for the circuit may be assumed to be from line *1* to line *2*, and it follows that the positive direction of the voltages for the two sides is from line *1* to neutral and from neutral to line *2*, and the meters are connected in accordance with these assumptions. The frequency meter, shown connected between line *1* and the neutral may be connected between the outside lines, if the voltage is not too high for the meter coils. The current transformers are so connected that the current which flows through

TABLE I—ENERGY REQUIRED TO OPERATE ALTERNATING CURRENT INSTRUMENT COILS AT 5 AMPERES OR 100 VOLTS

Instrument	Type	Current Element				Voltage Element			
		25 Cycles		60 Cycles		25 Cycles		60 Cycles	
		Volt-Amperes	Watts	Volt-Amperes	Watts	Volt-Amperes	Watts	Volt-Amperes	Watts
Ammeter	Induction	6.3	6.0	3.1	3.0				
Ammeter	Solenoid	8.0	5.0	8.0	5.0				
Graphic Ammeter	Relay	10.0	6.0	10.0	6.0				
Graphic Ammeter	Solenoid	16.0	5.0	16.0	5.0				
Voltmeter	Induction					10.9	9.7	10.9	9.7
Graphic Voltmeter	Relay					14.5	15.5	14.5	14.5
Graphic Voltmeter	Solenoid					31.7	28.0	31.7	28.0
Wattmeter	Switchboard	4.0	4.0	4.0	4.0	7.6	6.65	7.6	6.65
Graphic Wattmeter	Relay	3.5	3.5	3.5	3.5	9.7	9.7	9.7	9.7
Gr. Wm. Control Cir.	Relay					36.0	24.0	36.0	24.0
Watthour Meter	Switchboard	1.5	.7	1.5	.7	12.3	1.6	12.3	1.6
Power-Factor Meter	Iron Vane	1.5	1.5	1.5	1.5	13.3	12.1	13.3	12.1
Graphic P.-F. Meter	Relay	3.5	3.5	3.5	3.5	13.3	12.1	13.3	12.1
Reactive Factor Meter	Iron Vane	1.5	1.5	1.5	1.5	13.3	12.1	13.3	12.1
Graphic R. F. Meter	Relay	3.5	3.5	3.5	3.5	13.3	12.1	13.3	12.1
Frequency Meter	Induction					24.0	18.0	24.0	18.0
Graphic Freq. Meter	Relay					42.0	30.0	42.0	30.0
Synchronoscope	Iron Vane					13.3	12.1	13.3	12.1
Overload Relay	Induction	16.0	9.6	17.0	8.5				
Reverse Power Relay	Induction	18.0	11.0	17.0	10.0	14.5	2.8	20.0	2.5
Low Voltage Relay	Induction					13.3	12.1	13.3	12.1
Voltage Regulator	Solenoid					60.0	48.0	60.0	48.0
Cir. Bkr. Trip Coil	Light Pull	18.8		42.5					
Cir. Bkr. Trip Coil	Heavy Pull	32.0		65.0					
Cir. Bkr. Low Volt. Coil.								8.4	27.5
Direct Trip Relay	Normal Pos.	20.0	10.0	35.0	17.5				

the wattmeter is a measure of the combined current in lines 1 and 2 and, since the voltage coil of the wattmeter is connected to the voltage between one line and neutral, the meter reads the total power in both sides of the circuit. The ammeter may be changed from one side to the other by means of the ammeter switch, and the development of this switch shows how the circuits are made for the different positions. For the off position, the points 1, 3 and 2 are connected together and point 4 is open, and the currents from the current transformers in lines 1 and 2 combine and flow out on the wire connected to point 2 without any current flowing through the ammeter. For position 1, points 1 and 4 are connected together and points 2 and 3 are connected together so that the current from the current transformer in line 1 flows out on the wire from point 4, through the ammeter, thus giving a reading of the current in line 1, and then it combines with the current from the current transformer in line 2 which flows out on the wire from point 2. For position 2, points 3 and 4 are connected together and points 1 and 2 are connected together so that the current from the current transformer in line 2 flows out on the wire from point 4 through the ammeter, thus giving a reading of the current in line 2, and then it combines with the current from the current transformer in line 1 which flows out on the wire from point 2. The combined current from the two transformers flows through the power-factor or the reactive factor meter so that this instrument gives an indication of what might be considered as the power-factor of the sum of the loads on the two sides. The voltmeter may be changed from one side to the other by means of the voltmeter switch. The development of this switch shows how the circuits are made for the different positions. For the off position, all the points are open and the voltmeter is entirely disconnected. For position 1, points 2 and 3 are connected together and points 5 and 6 are connected together so that line 1 is connected to one terminal of the voltmeter and the neutral is connected to the other terminal and the voltmeter gives a reading of the voltage between line 1 and neutral. For position 2, points 1 and 2 are connected together and points 4 and 5 are connected together so that line 2 is connected to 1 terminal of the voltmeter and the neutral is connected to the other and the voltmeter gives a reading of the voltage between the neutral and line 2.

Autotransformer Motor Starters

H. D. James and R. E. DeCamp

The term "autotransformer starter" is applied to all alternating-current motor starters using autotransformers for obtaining a reduced starting voltage. When the power transformers can be provided with low-voltage taps for starting purposes, the same results are obtained, as far as the motor is concerned, but the problems which relate to the autotransformer itself are eliminated. This type of starter is used for squirrel-cage induction motors and synchronous motors. Usually it consists of autotransformers associated with switching mechanisms and provided with overload and low-voltage protection. Two methods of switching may be employed:—

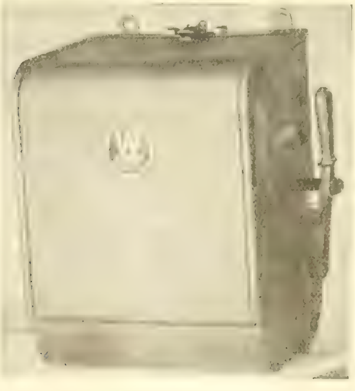


FIG. 1—MANUAL AUTOSTARTER

The starters are entirely enclosed and operated from the outside.

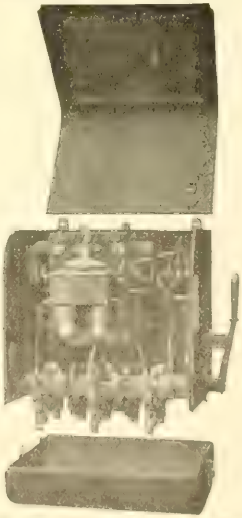


FIG. 2—INTERIOR VIEW OF MANUAL AUTOSTARTER

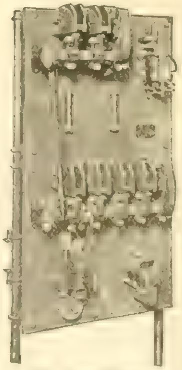


FIG. 3—AUTOMATIC AUTOSTARTER

These starters can be enclosed in a cabinet when necessary.

1—The more common method is to connect the motor directly to the low-voltage tap of the autotransformer for starting, and disconnect it entirely to change to full voltage. When this method is used with large, high-speed motors a heavy surge of current may take place when the motor is connected to full voltage.*

2—This difficulty with large motors can be avoided by connecting the motor to the full voltage taps without disconnecting the windings from the autotransformer by using preventive resistance or reactance coils to reduce the short-circuited current at the time of transfer from the starting to the line taps; or one end of the autotransformer winding may be disconnected from the line and the balance of the winding used as a choke coil during the transition, as shown in Fig. 5.

ADVANTAGES

An autotransformer is used instead of a resistance to obtain a reduced voltage for starting purposes because less current is taken from the line, due to the transformer action. The motor current is proportional to the voltage applied and to this must be added a small value to take care of the losses in the transformers. For instance, on the 65 percent tap, the saving in line current would be in the neighborhood of 30 percent. This is illustrated in Figs. 6 and 7. The advantage of using an autotransformer in starting is proportional to the percent reduction in voltage impressed upon the motor. It can readily be seen that if 90 percent of line voltage is required to start the motor, the saving in line current would be small when we consider the losses in the transformer itself. If 50 percent voltage is necessary to start, the saving would be quite large. The question naturally arises, if 90 percent of line voltage is required to start the motor why not connect the motor to the line and avoid the expense in the starter. This is frequently done and in many cases is the proper solution,* but the torque of the motor is thus increased 19 percent and this excess starting torque may throw off the belt or have some other undesirable effect. By using an autostarter, the starting torque can be adjusted as desired so that there is a decided advantage in having an autostarter even though the saving is small.

EXCITING CURRENT (MAGNETIZING CURRENT)

The autotransformer has an exciting current, in addition to its load current, which is composed of two principal items, the magnetizing current (a zero power-factor current) and the iron loss current (a 100 percent power-factor current). These two elements give a resulting current which may have a power-factor as high as the power-factor of the induction motor when it is connected to the line and the rotor is stationary. Referring to Fig. 8, the exciting current in the longer section of the autotransformer tends to flow in opposition to the load current. Since these two currents have power-factors which are not far apart, the load current tends to neutralize this magnetizing current and it is possible so to proportion the load current that there will be very little I^2R loss in the larger part of the transformer windings. This condition is only approached in practice but it illustrates the fact that the magnetizing current actually reduces the I^2R loss in the larger part of the transformer windings. The two currents add in the small end of the transformer winding so that, as the starting voltage is decreased, the effect of this magnetizing current becomes more and more apparent. The current taken by the motor, however, decreases with the decreasing voltage so that one effect offsets the other to a considerable extent.

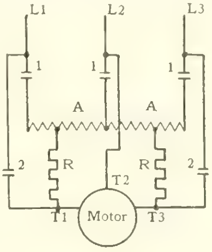


Fig. 4

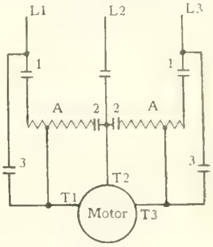


Fig. 5

FIG. 4—DIAGRAM OF AUTOSTARTER USING PREVENTIVE RESISTANCE

Switches *1* are first closed and low-voltage from the transformer *A* is supplied to the motor primary. Switches *2* are closed when the motor has accelerated and line voltage is impressed on the motor. The end section of transformer *A* is short-circuited through switches *1* and *2* but the preventive resistance limits the short-circuit current to a safe value. Switches *1* are then opened and the transformer disconnected. With this method the motor circuit is not opened during the transition period. The resistance may be replaced by a reactance. The action is then similar in effect.

FIG. 5—DIAGRAM OF AUTOSTARTER USING THE TRANSFORMER AS REACTANCE

Switches *1* and *2* are first closed, impressing low voltage on the motor. Switches *2* are opened when the motor has accelerated, and the end windings of the transformer act as reactances in the motor circuit. Switches *3* are then closed and full voltage is impressed on the motor. In this case the motor circuit is not opened up during the transition from low to high voltage.

The distribution of current in an autotransformer during the starting of the motor is illustrated by Figs. 9 and 10. Assume that the autotransformer starter has been designed for a 30 horse-power, three-phase, 440 volt motor and that the root mean square current of this motor per phase during acceleration is 82 amperes when connected to 65 percent of normal voltage (Fig. 9). Also assume that the exciting current of the transformer is 22 amperes. The motor current is divided between sections *a* and *b* of the transformer as follows:—Section *a*, 53 amperes and section *b*, 29 amperes. In section *a*, the two currents add making a total of 53 + 22 or 75 amperes. In section *b*, the currents subtract making a total of 29 — 22 or 7 amperes. Since section *b* represents 65 percent of the total winding, the total heating in the transformer is reduced by the exciting current. If the motor is connected to the 80 percent tap, (Fig. 9) the heating in the transformer is still less, although the motor current is greater, because section *a* which carries the extra current is only 20 instead of 35 percent of the total winding.

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*For a discussion of this, see papers by H. D. James, R. E. Hellmund and A. A. Gazda, A. I. E. E. Transactions of Feb. 1917, pp. 253, 321 and 330.

*See "Manual Starters for Small Squirrel-Cage Induction Motors" in the JOURNAL for December, 1919.

Now assume that the 30 horse-power starter was used for starting a five horse-power three-phase, 440 volt motor. The full-load current of this motor is approximately 15 amperes when connected to 65 percent of normal voltage. This motor current is distributed in the transformer windings as follows:—Section *a*, 10 amperes and section *b* 5 amperes. With 22 amperes exciting current, the total current in section *a* will therefore, be 10 + 22 or 32 amperes as compared with 75 amperes for the 30 horse-power motor. The current in section *b* will be 22 — 5 or 17 amperes total as compared with 7 amperes for the 30 horse-power motor. The heating effect of the current in section *b* is, therefore, about six times as great for the five horse-power as for the 30 horse-power motor. If the five horse-power motor is connected to the 80 percent tap, the difference will be still greater.

These two examples show that a large starter used on a small motor may heat up more than if used with the motor for which it is designed. The two above examples mentioned are exaggerated and the currents do not cancel to the full extent shown due to the differences in phase angles; the examples are simplified to make them easy to follow. In making applications of starters to small motors, care should be exercised and, when in doubt, the matter should be referred to the motor builder. It is evident that, if the exciting current were zero or had a very small value, an advantage would be gained by using a large starter with a small motor, in the same way that a resistor will heat up less with a small motor than a large one. This, however, makes a very poor transformer when used with a motor of normal rating. The exciting current should be made large enough to reduce the heating materially on the 65 or 80 percent tap. Most motors are started on

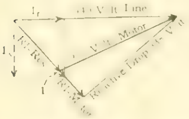


FIG. 6—SINGLE-PHASE DIAGRAM OF CIRCUIT WITH RESISTANCE FOR STARTING TO GIVE 80 PERCENT OF LINE VOLTAGE AT THE MOTOR TERMINALS, ROTOR LOCKED

Motor and Resistance Characteristics.

Resistance total 2.68 ohms.
Reactance 3.20 ohms.
Impedance 4.18 ohms.
Line current 105 amps.
Wattless current 80 amps.
Power taken from the line, 29.6 kw

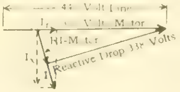


FIG. 7—SINGLE-PHASE DIAGRAM OF CIRCUIT WITH AUTOTRANSFORMER FOR STARTING TO GIVE 80 PERCENT OF LINE VOLTAGE AT THE MOTOR TERMINALS, ROTOR LOCKED

Motor Characteristics.

Resistance 0.9 ohms.
Reactance 3.2 ohms.
Impedance 3.32 ohms.
Line current 84 amps.
Wattless current 80 amps.
Power taken from the line, 10 kw

The above diagrams show the advantage of using a transformer instead of a resistance for squirrel-cage motor starting. A similar diagram with 65 percent of line voltage at the motor terminals shows that the power taken from the line is nearly five times that taken with an autotransformer and the current 30 percent greater. The transformer characteristics are neglected in the above analysis.

the 80 percent tap and, therefore, the maximum benefit from this exciting current is obtained.

Another way to analyze this problem is to consider that the magnetizing current taken by the motor is fixed for a given voltage. The autotransformer furnishes this magnetizing current to the motor. In the section of the transformer between the motor terminals, the magnetizing current required by the transformer is approximately 180 degrees out of phase relation with the magnetizing current taken by the motor. This results in the magnetizing current of the one cancelling that of the other. If these magnetizing currents are equal there will only be a small flow of current, due to difference of phase relation between the currents.

The section of the transformer winding between the motor terminals and the line, designated as section *a* in Figs. 9 and 10, has a magnetizing current flowing through its windings which is not neutralized by the magnetizing current of the motor. The two magnetizing currents add vectorially and tend to heat these windings due to the I^2R loss. If the resistance of this portion of the winding is kept low, the actual wattage loss is also low, this being only a question of design.

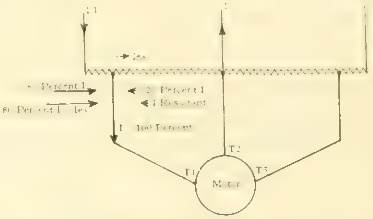


FIG. 8—DIVISIONS OF CURRENT IN AN AUTOTRANSFORMER

I = Load Current.

I_{ex} = Excitation current of the transformer.

This diagram shows how the exciting current cancels out the load current in the larger part of the autotransformer winding. The load current represented as 100 percent divides in proportion to the tap ratio. In the case shown, with the 80 percent tap, 20 percent of the load current tends to flow through the large number of turns and 80 percent through the small number of turns. But the exciting current and load current in the large number of turns oppose. During starting, when the power-factor of these currents is approximately equal, they subtract almost directly. The net resultant current, therefore, in the large number of turns is small and consequently the heating effect is small, since the heating varies as the square of the current. These currents add in the small number of turns, but since this is a heavy winding designed to carry load current, the additional heating effect is small. The same effect is produced if the autotransformer is connected on the 65 percent tap.

Now consider the current taken from the line. This is made up of two components, one the energy component and the other the magnetizing component. If the magnetizing current of the transformer subtracts from the magnetizing current of the motor in section *b*, the heating effect in section *b* of the transformer windings is comparatively small. By properly designing the short section of the transformer winding (section *a*) so as to keep down the I^2R loss, the actual loss in the transformer can be made low. This condition is obtained by having the transformer exciting current approximately equivalent to the exciting current of the motor and holds good for only one particular size and design of motor. When designing commercial autotransformers, it is necessary to select a certain range of motor sizes and speeds, and select a motor magnetizing current which represents the average value and then make the magnetizing current of the transformer equal to this value. The windings of the transformer must be proportioned for the worst condition, which is obtained in section *a* of the winding when the largest motor is being used and in section *b* of the transformer winding when the difference between the motor magnetizing current and the transformer magnetizing current is a maximum. An additional allowance must also be made for small differences in phase angles.

It will be seen from the above that the exciting current of a properly designed autotransformer for intermittent starting should be much larger than for power transformers. This excess magnetizing current will overheat section *b* of the transformer winding, if left on for any considerable length of time without the motor load, because there is no cancellation of current in this section of the transformer winding.

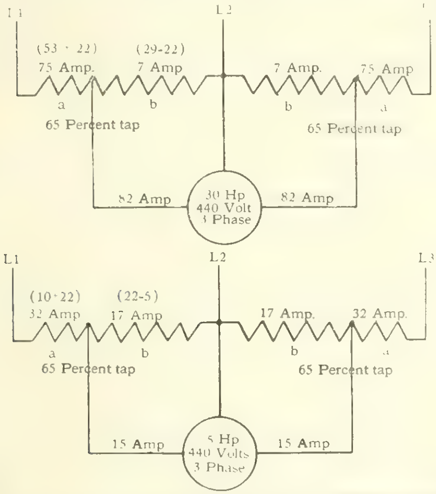


FIG. 9—30 HP AUTOTRANSFORMER STARTER CONNECTED TO 65 PERCENT OF NORMAL VOLTAGE

The diagram shows the distribution of current during the starting period based on the root mean square value of the motor current during acceleration. It is assumed that the exciting current is 22 amperes and is approximately in phase with the motor current. This assumption is not strictly correct, as the phase angles of the various components of the current are unsymmetrical and the current values do not add or subtract directly. The current components also differ in each of the two phases. The diagram is made approximately correct for purposes of illustration and, therefore, does not take into account the minor difference enumerated above.

The additional current taken from the line by the autotransformer is very small. It is found by actual test that the transformer current adds approximately five percent to the power input when the motor is connected to 65 percent of line voltage.

The exciting current varies with the voltage and the frequency. Each time the magnetism in the iron reverses, it generates a voltage in the transformer windings. The product of this magnetism, multiplied by the number of turns in the coil, multiplied by the frequency, must balance the line voltage. Since the number of turns in the coil has a fixed value for a particular design, an increase in voltage at a constant frequency would require a corresponding increase in magnetism in order to balance this increased line voltage. If the voltage remains constant and the frequency decreases, an increase in magnetism would be required to make the product constant. When the iron in the autotransformer is worked hard, as is the case in autotransformer starters, an increase in magnetism requires a considerable increase in exciting current, the iron loss going up quite rapidly at this part of the magnetization curve. Therefore, any unusual increase in voltage or decrease in frequency will cause a proportionally larger increase in the exciting current. Standard autotransformer starters are designed and guaranteed to operate successfully on ten percent variation in the line voltage, provided the frequency remains constant.

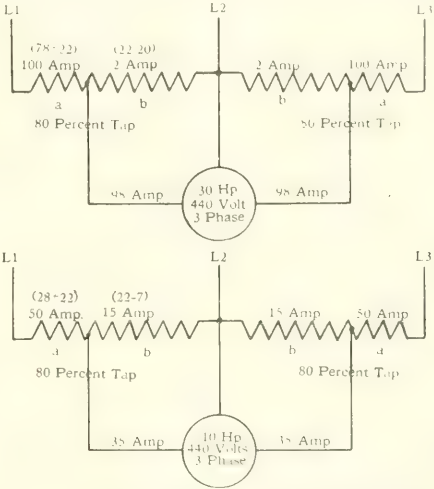


FIG. 10—30 HP AUTOTRANSFORMER STARTER CONNECTED TO 80 PERCENT OF NORMAL VOLTAGE

The diagram shows the distribution of current during the starting period based on the root mean square value of the motor current during acceleration. It is assumed that the exciting current is 22 amperes and approximately in phase with the motor current. This assumption is not strictly correct as the phase angles of the various components of the current are unsymmetrical and the current values do not add or subtract directly. The current components also differ in each of the two phases. The diagram is made approximately correct for purposes of illustration and, therefore, does not take into account the minor differences enumerated above.

MOTOR TORQUE

The torque of an induction motor varies as the square of the impressed voltage. It is usual to express the starting characteristics of an induction motor by stating that it has a certain locked torque. This is the torque exerted when the rotor is stationary and normal voltage is applied to the primary windings. This torque is usually expressed in terms of the full-load torque.

Thus a motor having a locked torque of two, means that the torque at zero speed is equal to twice full-load torque with normal voltage on the primary. If 70 percent voltage were applied to the motor primary, the motor would exert a torque equivalent to two multiplied by (0.70^2) or 98 percent of full load torque. This starting torque is independent of the method employed for obtaining the reduced voltage. Some times the claim is made that a motor will start with one starter and not with another, the inference being that the starters have different effects on the motor torque. This is only true if the starters provide different voltages at the motor terminals. The tap voltages on an autotransformer are usually expressed in percentage of full voltage. These percentages are not exact, as it is necessary to compensate for the voltage drop through the transformer. This compensation differs with different motors owing to the variation in the starting current. It is, therefore, improbable that two different types of starters would give exactly the same voltage at the motor terminals and this is probably the explanation of the failure of one type to start the motor, while the other was successful. The difference in voltage may appear trivial but it must be remembered that the effect varies as the square of the difference in voltage and that a little extra torque may be all that is required to cause the motor to start rotating. As soon as the motor commences to rotate, the friction decreases and the torque of the motor gradually increases, so that the critical period is the instant of starting. Some motors exert a slightly different torque when starting, depending upon the location of the rotor slots relative to the primary winding. This variation of starting torque is usually quite small but as it may be appreciable in particular motors, it should be taken into consideration.

TABLE I—TEST ON A 100 HORSE-POWER, 60 CYCLE, 3 PHASE, 220 VOLT MOTOR WITH AUTOSTARTER

Showing voltages and starting torques of the motor with balanced and unbalanced tap connections.

	Line Volts No Load	Line Volts With Load	Volts at Motor Terminals	Motor Torque
Test on 65% Tap, Motor Locked.				
L1 to L3	230	199	118.5	278 lb.-ft.
L2 to L3	220	196	120	
L1 to L2	229	194	122	
Test with One Winding Connected on the 65% Tap and the Other on the 80% Tap.				
L1 to L3	220	190	130	334 lb.-ft.
L2 to L3	229	184	141	
L1 to L2	229	193	121	
Test With 80% Tap.				
L1 to L3	229	188	141	410 lb.-ft.
L2 to L3	229	185	139	
L1 to L2	229	188	141	

These tests show that the transformers in "V"-connection give nearly balanced voltages with balanced taps. The starting torques obtained with unbalanced taps is approximately the average of the two torques which would be obtained with either balanced connection.

ADJUSTMENT OF STARTING VOLTAGE

The starting voltage can be adjusted by changing the starting connections from one transformer tap to another. If the autotransformers are provided with 65 and 80 percent taps, 42 and 64 percent of the locked torque of the motor can be obtained when starting. For the smaller motors less than 42 percent of the locked torque is not necessary but the larger starters sometimes have a 50 percent tap which provides 25 percent of locked torque for light starting conditions. Where intermediate values of starting torque are necessary, they can be obtained by connecting one starting lead to the next higher starting tap. For instance, if one side is connected to the 65 percent tap and the other side to the 80 percent tap, an intermediate value of starting torque will be obtained with an intermediate value of power input. Connections of this kind unbalance the phases so that more current is taken from one phase than from the other. The amount of this unbalancing, however, is considerably less than the difference in voltages after the motor begins to revolve. In no case is the current taken from either phase greater than would be taken if both leads were connected to the higher voltage.

TABLE II—COMPARATIVE TEST ON A THREE-PHASE, 60 CYCLE, 6 POLE MOTOR

Showing starting torque with autotransformers in open V and in Y with 100 percent voltage applied to transformer windings.

Motor Torque	Three Transformers Y-Connected	Two Transformers Open V-Connected
At 65% Voltage	33.5% of locked torque 34.3% of locked torque	33.1% of locked torque 34.0% of locked torque
At 80% Voltage	52.0% of locked torque 52.4% of locked torque	51.7% of locked torque 52.2% of locked torque

Table I gives the results of a test made with both balanced and unbalanced connections and shows the torques and voltages at the motor terminals. The use of two autotransformers in a V-connection for starting three-phase motors is sometimes criticized on the grounds that it produces unbalanced voltages at the motor terminals and, therefore, decreases the starting torque of the motor. The tests in Tables I and II show that this small amount of unbalancing may be neglected. The torque exerted by the motor in starting from rest is practically the same as with three autotransformers connected in delta. The variations in the starting torque exerted by different motors of the same design due to irregularity of manufacture is considerably greater than the effect of slight unbalancing and the point is thus theoretical rather than practical. The advantage of two transformers rather than three in reducing complication and simplifying the connections is a practical consideration.

TIME-TEMPERATURE CHARACTERISTICS

The Electric Power Club has agreed that the standard starting period for manually-operated autotransformer starters is fifteen seconds. This is an arbitrary designation and means nothing until a careful study is made of the autotransformer when starting a motor. It does not mean that, if the startihg period exceeds fiftenn seconds for one start, the transformer will be injured. In 1912, the National Board of Fire Underwriters agreed with the manufacturers to use an arbitrary "stand" test for autotransformer starters. This test consisted in connecting the line wires to full voltage and applying three times full-load motor current to the starting tap, the starting tap to be selected from 40 to 65 percent of line voltage. With these connections, the line voltage was impressed on the starter for fifteen seconds every four minutes. The remaining three and three-quarter minutes permit the transformer to cool. This test was repeated for one hour, which is equivalent to fifteen starting periods, and was based on the assumption that the heating effect in the starter was equivalent to that which would occur in starting under abnormal conditions. The test under these extreme conditions was to determine the probability of fire hazard.

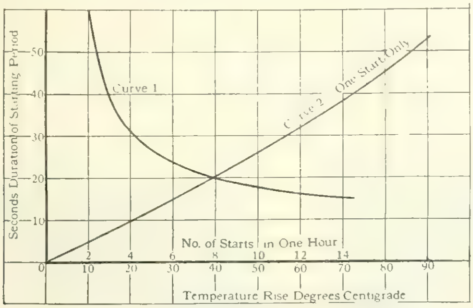


FIG. 11—TYPICAL TEMPERATURE CHARACTERISTICS OF AN AUTOTRANSFORMER

Curve *1* shows the maximum number of starts allowable in one hour for a given duration of the starting period, based on the Underwriter's specifications. Curve *2* shows the temperature rise by resistance for a single start of a given duration, based on the Underwriter's specifications of full load current on the 65 percent tap.

Since that time, manufacturers have been designing their autotransformers to meet this test. It should not be assumed, however, that a commercial starter can be applied where it is necessary to start as frequently as indicated by this test. Standard starters may be used for accelerating motors where the starting period is approximately fifteen seconds and not over six or eight starts are made without allowing the transformers to cool down to the room temperature. Several starts of a longer period, even as long as thirty seconds, can be made if the transformer is cold and the starts not repeated too often. Fig. 11 indicates the relative increase in temperature under different starting conditions.

OVERLOAD AND LOW-VOLTAGE PROTECTION

Autotransformer starters are usually provided with overload relays having two coils, one coil connected in each of two phases. The relays are provided with oil dashpots. The results of tests made on relays of this type, show that they have a considerable time element which is sufficient for most applications. It is desirable to set this relay for as low a current value as operating conditions will permit. The lower the setting the better the protection afforded the motor.

Autotransformer starters of the manual type are provided with low voltage protection consisting of a magnet which releases the switch element and stops the motor when there is an abnormal drop in voltage. The coils are guaranteed for operation on ten percent above normal voltage at rated frequency. In some cases the voltage during the night has been 25 or 30 percent in excess of normal. This may destroy the coil, particularly if the air-gap in the iron circuit is not in first class adjustment. Where abnormally high voltages of this kind occur, the minimum voltage is often above normal. In such cases, special coils can be furnished to suit the range of voltage obtained on the circuit.

USE ON OTHER VOLTAGES AND FREQUENCIES

Autotransformer starters can be used on other voltages and frequencies than those for which they are rated. In making such interchanges, three elements are affected, viz:—the autotransformer; the low voltage coil; and the overload relay.

The low voltage coil is the most sensitive to changes in voltage or frequency, as excess voltage will cause it to overheat, and on low voltage it will fail to hold. It is, however, independent of the size of motor, in fact, coils of the same size may be used on a complete line of starters. A decrease in voltage, will counterbalance a decrease in frequency. For instance, a 550 volt 60 cycle coil will probably operate successfully on a 460 volt 50 cycle circuit, allowing a ten percent variation from this value, which is within the normal guarantee. For other line characteristics, the proper coil can easily be substituted for the one in the starter.

Autotransformers should not be used on voltages more than ten percent in excess of their normal rating but they may be used for any voltage of less value, provided the current of the motor does not exceed the normal value for that particular transformer. For instance, a 30 horse-power, 440 volt autotransformer starter can be used with a 15 horse-power, 220 volt motor by changing the low voltage coil. It is obvious that, if the current value is kept the same, the overload relay will not be affected. If the frequency is decreased the voltage should also be decreased as for example, the 550 volt, 60 cycle transformer can be used on 440 volt, 50 cycles for a motor which is proportionally smaller.

If the frequency is above normal, as when a 25 cycle starter is used on a 40 cycle circuit, the transformer will be satisfactory and, if the size of motor is kept the same, the starter can be used by changing the low voltage coil, but a change in frequency over this range may also require a change in the shading coil on the magnet if the best results are to be obtained.

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country.

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor

JANUARY 1920

Repairing Loose Housings on Split Frame Motors

When the two halves of a split-frame motor are bolted together for the machining of the housing fit, a liner of sheet steel about 0.017 inch thick is placed at the split to insure a good clamping action on the housing when the two halves of the motor frames are bolted together. During the overhauling period, or when motor troubles have developed and frames are opened up to take out the armatures, there is a possible chance of losing this clamping action in reassembling, due to one or more of the following reasons:

a—Frame bolts not drawn up tight.

b—Leaving off the lock washers.

c—Using a poor grade of bolt which will stretch.

d—Presence of dirt at split of motor frame.

Motors operating under the above conditions, due to the pounding action of the armature and hammer-blows in passing over the rail joints, will soon develop considerable wear of the housings and housing seats, as well as the tap bolts and tapped holes in the housings. This type of housing is shown in Fig. 1.

This trouble has been one of the main factors leading to the development of the present standard box type motor, with housings that have a tight driving fit in the ends of the solid frame which has practically eliminated loose housings in railway motors. See Fig. 2. A number of methods for repairing loose housings in split frame motors, some temporary, others permanent, have been tried out on various properties and found to work very satisfactorily. Some of these methods are outlined below:—

BUILDING UP WORN HOUSINGS

With Canvas Duck—Strips of canvas duck treated with white lead are placed on the worn housing, building it up to such a diameter as to insure a good tight clamping action of the two halves of motor frame when bolted together. In order to check whether the two halves of the frame of the motor are clamping the housings, it should be possible to get a 0.005 to 0.007 in. feeler between the frames at the split when they are bolted together with built-up housings in place.

With Advertising Sign Cards—Strips of advertising sign cards held in place by shellac are fastened to the worn housing, building it up to such a diameter as to insure a good tight clamping action of the two halves of the motor frame when bolted together.

With Electric or Oxy-Acetylene Welding—When the housing is not too badly worn, if made of malleable iron, it can be built up by means of the electric or oxy-acetylene welding process, after which it is machined to fit the housing seat in the motor frame, plus enough allowance to insure a good tight clamping action of the two halves of the motor frame when bolted together.

With a Shrunk on Steel Ring—The worn tap bolt holes should be bored out large and cast iron (which has been found to give best results) plugs driven tightly in these enlarged holes. The worn housings are then turned down and a steel ring about ⅜ inch thick is shrunk on the housing. If the housing has a double flange one of these must be turned off and a new flange made on the shrunk on ring. It is then turned down to such a diameter as to insure a good tight clamping action of the two halves of the motor frame when bolted together. New holes are drilled and tapped in the housing through the shrunk on ring into the cast iron plugs to receive the tap bolts.

BUILDING UP HOUSING SEATS IN MOTOR FRAME

With Electric or Oxy-Acetylene Welding—The housing seat in the motor frame is built up by means of the electric or oxy-acetylene welding process and rebored to a smaller diameter, to fit the worn housing (which should first be trued up) with enough allowance to insure a good tight clamping action of the two halves of the motor frame when bolted together.

With Metal Liner—The housing seat in the motor frame is bored out and then built up by means of a semi-circular steel liner, riveted in place, after which it should be welded at several points. The housing seats are then rebored to fit the worn housings (which should first be trued up) with enough allowance to insure a good tight clamping action of the two halves of the motor frame when bolted together.

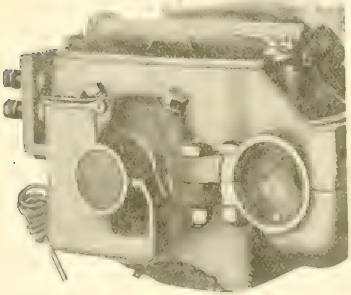


Fig. 1—Split Frame Motor with Tap-Bolt Type Housing

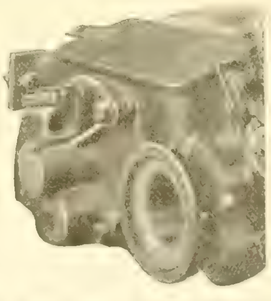


Fig. 2—Box Frame Motor with Driven-In Type Housing

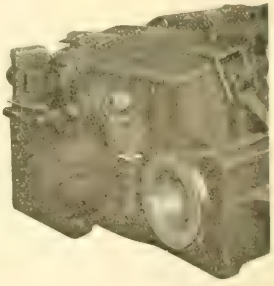


Fig. 3—Split Frame Motor with Through-Bolt Type Housing

MACHINING FRAME AT SPLIT OF MOTOR

Machine off enough metal at the split of both halves of the motor frame to insure a good tight clamping action on the worn housing of both halves of the motor frame when bolted together. When this method is used it will be necessary to rebore the pole faces, to see that the correct air-gap is maintained.

REPAIRING WORN BOLT HOLES

In connection with the repairs of worn bearings, the following methods have been used to fix up the worn tap bolt holes:

a—Use a longer tap bolt, which will engage the lower threads of the tapped holes in the housing that have not been damaged by the loose shorter bolts.

b—Fill up the old worn holes by welding in, preferably Tobin bronze, and reboring and retapping new holes.

c—Drill out the worn holes to a larger diameter and threading in a steel plug, welded at edges. This plug is then drilled and tapped to take the standard size bolts.

d—Retapping worn holes for next larger size bolts.

e—Where shrunk on rings are used, drill out large and drive cast iron plugs tightly into these enlarged holes. Drill and tap new holes in the plugs.

THROUGH BOLT TYPE OF HOUSING

A new type of housing, arranged with through bolts as shown in Fig. 3, is being used to replace the old badly worn tap bolt type of housing. This type of housing is also used on new split frame motors of more recent design. With this through bolt construction, housings can readily be kept in good condition, as there are no tapped holes in the housing to wear, should they tend to work loose in service. If, on account of lack of maintenance, the threads of the through bolts become worn or damaged, they can readily be renewed at a small expense.

PRECAUTIONS TO KEEP HOUSINGS FROM WEARING

On motors of the split-frame type, using either the new tap bolt type, revamped tap bolt type, or the new through-bolt type of housing, to insure against housings working loose, it is advisable:—

a—To keep frame bolts and housing bolts drawn up tight.

b—To see that lock washers are on all bolts.

c—To use a good grade of heat treated steel bolts.

d—When assembling motors remove all dirt at the split.

e—To keep armature bearings in good condition.

f—To inspect bolts regularly and systematically, and keep them drawn up tight.

John S. Dean.

THE JOURNAL QUESTION BOX

[illegible] bers are invited to use this department as a [illegible] bjects. Questons concerning general engineering [illegible] practice and questions regarding apparatus or [illegible] ired for particulars needs will be answered. [illegible] garding design or redesign of individual pieces [illegible]

To receive prompt attention a self-address, stamped en- [illegible] a complete understanding of the problem should be furnished. A personal reply is mailed to each questioner as soon as the necessary information is available; however, as each queston is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply.

1840—Induction Regulator—Why is the exciting current so high in an induction regulator? Why is the secondary in single-phase regulators wound in open slots and the tertiary in closed slots?
W.K.G. (PA.)

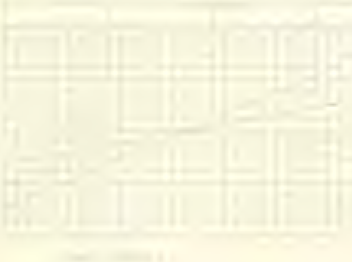
An induction regulator resembles an induction motor in that it has an air-gap between the primary and secondary core. The exciting current is, therefore, comparable with that of an induction motor rather than with that of a transformer, which has no air-gap in the magnetic circuit. Main windings are wound in open slots so that form wound coils can be used. This type of coil can be wound, insulated and placed into the slots more easily than any other, particularly when high voltages are involved. The tertiary coils, requiring practically no insulation, are put into partially closed slots so as to reduce the reluctance at the air-gap and thus reduce the exciting current.
E.E.L.

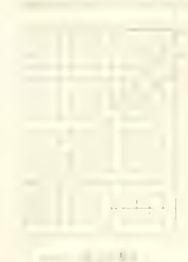
1841—Wrenches for Mine Locomotives—What type and style of wrenches are used to tighten gear bolts on the gears on the driving axle of mine locomotives? Can these be purchased from the locomotive manufacturer? Usually these are in a very hard and close place to get at and to get them perfectly tight is difficult.
F.H. (W.VA.)

The manufacturers of gears for locomotives do not in general furnish wrenches for removing split gears, for the reason that most of the operators have their own methods. It is also considered much easier for the operator to make his own wrench to suit any particular gear. The gears, when applied by the manufacturer on the locomotive, are tightened before the motors and other parts are assembled on the locomotive. They use, in all cases where poss [illegible]

In some cases it will be found possible to use an "S" wrench. A large bituminous coal operator was asked recently how he tightened split gear bolts. He answered that in all cases the wheels and axles together with the motor, are removed from under the locomotive. The gear case and motor are then removed and the bolts tightened by the use of a socket wrench. This method of tightening gear bolts, as used by this operator, is considered the best in order to insure that gears will be tight on the axle. It not only provides greater accessibility for tightening the gears on axle, but also permits a very thorough inspection on the gearing and motors. Manufacturers of gears have found from experience that in railway and mining fields, split gears will always be a source of trouble. Practically all railway operating companies are now standardizing on solid forged steel gears, and this is also true of several large coal operators.
D.E.S.

[illegible] Mazda lamp is connected in series with a 60-watt carbon lamp, and the voltage varied from 10 percent above. to 10 percent below normal voltage, how will the resistance of the circuit vary, or to what extent will the negative temperature-coefficient of the carbon filament compensate for the positive coefficient of the tungsten filament?
H.F. W. (COL.)





The effect of a change of voltage upon the resistance of tungsten metallized filament and carbon lamps is shown in Fig. (b). The relative distribution of voltage between carbon and tungsten lamps in series is shown in Fig. (a), both of these curves being worked out on a percentage basis in order to be applicable to any size of lamp. The resistance of any lamp at normal voltage can of course be calculated from the watt and voltage rating. For example a 60 watt, 110 volt lamp equals $E^2 \div W$ $=202$ ohms. At ten percent above normal voltage of the two lamps in series, from Fig. (a) the Mazda lamp will have 112.5 percent normal voltage across it and the carbon lamp will have 107.5 percent of normal voltage across it. Then from Fig. (b) the relative percent resistance of the tungsten lamp will be 105.3, or 212.7 ohms, while the carbon lamp will be 99.3 percent of normal or 200.6 ohms. This will present an increase in the total resistance of the circuit of 2.3 percent. The curve shows that the carbon lamp has almost the same effect on the Mazda as a constant resistance would have, since the carbon lamp has very nearly a constant resistance throughout a considerable voltage range around normal. Values for any other voltage can be readily determined from the curves.
E.J.E. AND E.G.W.

1843—Elevator Operations—Please give your opinion as to the idea of service, etc., with 14 elevators—if each one were equipped with a current relay in the main elevator feeders or a subdivision of the main current of all elevators on each starting panel in circuit with the main panel spool to open the spool circuit of each elevator at any time the total current used by all the elevators exceeds a determined amount. The idea is to hold for an instant the starting of any elevator if the current limit is exceeded by those starting or in operation; say if the needle of the main ammeter sometimes swings to 1500 to hold it down to the point where it would not exceed 1000 amperes.

J.E.M. (MICH.)

The service would be materially and probably seriously affected by a current limit device such as outlined in the question. The elevators would be held too long in starting, as the current peaks of the machines already under way would cover a period sometimes of three or four seconds. Of course, all of the elevators do not leave the starter simultaneously, but after all elevators are operating at floors above the first you may readily obtain a condition wherby a number of elevators would be accelerating at the same time, which cause the current relay to maintain an open circuit in the control feed or certain other elevators, in which case the operator, after moving the car switch to the running position, would never be sure just when his car would start. In cases where the operators do not make accurate landings and have to "inch" to the floor level, this condition would be a source of annoyance and considerable loss of time. It would also create a bad impression of the elevator equipment. Perhaps the most important consideration is that these interruptions in the service would occur during peak loads at rush hours. If the elevator load is too heavy for the power supply at certain periods, it will be better to shut down one or more elevators at that time and handle the traffic with all possible facility with the remaining cars. If the power is supplied by a central station, there should be no limit to the power supply and all of the cars would be available at the rush hours. The only time there would be any demand for a current relay scheme, as outlined, would appear to be in case of elevators operating from a private source of supply.

H.L.K.

1844 — Heating of Porcelain Insulators—What is the maximum temperature to which porcelain of the wet process make and used for bus supports, etc., is submitted during manufacture? What is the maximum temperature to which such porcelain can be raised both slowly and suddenly after manufacture without undue risk of cracking?

H.E.C. (PA.)

The maximum temperature reached in the firing of wet process electrical porcelain is generally 1330 to 1350 degrees C. (2426 to 2462 degrees F.) The last 30 to 50 degrees rise are a matter of several hours so as to make sure the thickest parts of the porcelain are well vitrified. Most electrical porcelain may be raised from room temperature to 500 or 600 degrees F. suddenly without much danger of cracking. It may also be cooled from such temperature rapidly. A great number of continuous repetitions would in time cause a break down. If the heating and cooling were done slowly, however, the process could be carried on indefinitely. Good porcelain should stand plunging from boiling into ice water a great number of times. If porcelain is heated to 500 degrees F. and then quenched in ice water, immediately placed in a temperature of 500 degrees again, and the cycle repeated indefinitely, the glaze will usually show signs of cracking after 10 or 12 cycles, and the body itself will usually begin to show signs of deterioration after a few more cycles. It should be taken into consideration also, that the design of the porcelain will affect the resistance to sudden heat change to a large extent. Designs changing thickness of section rather sharply will not stand temperature changes so well as porcelain of more uniform section.

R.A.K.

1845—Exploring Coil—I am desirous of making a temperature test on a 300 hp, 60 cycle, 220 volt, slip ring motor. Please inform me as to the following points:—(a) Would a resistance coil made of insulated nickel wire wound on a strip of mica, be suitable for a resistance unit to place in a slot between the upper and lower halves of the coils. (b) What should be the size of the wire? (c) Is there any wire that would be better than nickel? (d) Can resistance measurements be made when the machine is running or would a voltage be impressed at the ends of the resistance unit that would damage the Wheatstone bridge, or render the measurements made in this way inaccurate.

G.A.S. (MINN.)

A suitable exploring coil can be made of insulated nickel wire. The wire should be about No. 30, so that it will carry the current which may flow through it when measuring the resistance, and yet not increase appreciably in resistance. An exploring coil made of No. 38 single silk-covered copper wire is often used. About 45 feet is used and wound on the desired insulation with the leads made of copper ribbon running through the coil. It must be wound in two layers and the leads brought out together, so that the voltage induced in one layer and one lead. is equal and opposite to that induced in the other layer and lead. With this condition, the resistance may be measured satisfactorily when the machine is running.

C.R.C.

1846 — Dynamic Braking — Can dynamic braking be employed with single-phase, two-phase and three-phase squirrel-cage induction motors? Please explain how?

P.C.W. (OHIO)

Dynamic braking with induction motors divides itself into two classes. First; braking to prevent a load (such as a car descending a grade) from greatly exceeding its normal speed, or running away. Second; braking for the purpose of bringing the motor and its load from full speed to standstill. Dynamic braking of the first class can be accomplished with any induction motor by simply leaving the primary connected to the line and allowing the load to run the motor slightly above synchronism as an induction generator. For a given percentage increase in speed above synchronism the braking torque will be approximately equal to the torque when operating as a motor at the same percentage decrease in speed, or slip, below synchronous speed. Braking of the second class cannot be accomplished with a single-phase squirrel-cage motor, but can be accomplished with either a two-phase or a three-phase squirrel-cage induction motor by reversing two of the primary leads (that is by reversing the direction of rotation of the magnetic field set up by the primary). The primary circuit must be opened as soon as the motor comes to rest or otherwise the motor will speed up in the opposite direction. In the case of large size squirrel-cage induction motors care should be taken not to reverse the primary field at full voltage, as the current at reversal will be larger than the locked current taken by the motor at the same voltage, and this large current would be apt to damage the windings of the motor, either by distorting them or over heating them.

G.T.S.

1847— Single-Phase Self-Starting Synchronous Induction Type Motor —In connection with an X-Ray outfit, there is a small motor used for driving a commutating device at synchronous speed in connection with the alternating-current direct-current supply to the X-Ray tube. This motor is self-starting on closing the main switch, and runs synchronously on the 200 volt, 50 cycle single-phase mains, taking about 200 watts. There is no auxiliary direct-current supply available. The external appearance and size of the motor is similar to that of an alternating-current induction fan motor. How is the self-starting synchronous feature obtained?

F.W.W. (AUST.)

This is an ordinary split-phase induction motor with definite polar projections on the rotor. It starts as an induction motor and runs as an attraction motor i. e. the polar projections follow the rotating field and will remain in synchronism up to a considerable load.

G.H.

1848— Transparent Non-Inflamable Sheet Insulator—I would like to get some transparent sheets of the general nature of bakelite. Bakelite is not made in sheets in its transparent state and perhaps it would be too brittle for my purpose if it were. Celluloid is too inflamable for what I want. A mixture of celluloid and bakelite might do, but I suppose no one would be interested enough to try them or offer an opinion. Do you know of anything that is not a conductor of electricity and that is transparent, colored and made in sheets around 1/16 inch thick that can be bent without breaking.

G.E.W. (ENGLAND)

Cellulose acetate is the closest approach to a non-inflammable, transparent, flexible insulator. Unfortunately it is not entirely free from objection as an insulator in that it is somewhat hygroscopic. The non-inflammable celluloids are practically the same thing as cellulose acetate.

H.C.P.W.

NOTICE TO SUBSCRIBERS

Copies of the "Table of Contents" and of the "Topical Index for 1919, are now available and will be forwarded to Journal subscribers on request. With this Index another five year period is begun, the Index for 1918 having been a complete Five Year Index. The Electric Journal is unique in that any article which has appeared in any of its volumes can be quickly located by referring to but three indexes. The price of the Index for 1919 or the Five Year Index is 25 cents per copy.

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THE BENJAMIN INDUSTRIAL LIGHTING BOOK.

The Benjamin Electric Mfg. Company of Chicago has published a book on Industrial Lighting that embodies much practical information for applying the principles laid down by illuminating engineers as the best practice in the lighting of buildings and areas devoted to industrial uses. The book has been prepared with a view of being helpful to anyone whose objective is the attainment of correct industrial lighting. It is a response to the demand for genuine service to all departments of industry, seeking to raise standards of production, reduce accidents, and spoilage, and to make the task of the worker more acceptable through the application of higher lighting intensities. The considerations governing the selection of lamps and reflectors are explained in simple terms. There is a chapter on general illuminating information, with tables and definitions which reduce to simple terms the complex formula out of which correct deductions with regard to the specification of lamps and fixtures are resolved. There is a table giving the foot-candle intensities desirable as worked out from a consensus of the best opinions of illuminating engineers and physicists, and a complete presentation of the electrical symbols used on architect's drawings. The catalog data relating to Benjamin industrial lighting equipment is arranged in orderly sequence, carefully indexed, and gives the reader a comprehensive idea of the material available to meet a wide range of industrial lighting requirement. A feature of unusual interest is the charts of industrial fixtures which present a study of reflector contour, light distribution diagram and lamp so that the specification for any particular use is easily arrived at without recourse to any data other than that given in this book. Numerous examples of industrial lighting requirements, with actual photographic reproductions of results, add greatly to the usefullness of this very practical book on lighting requirements. Copies of this book will be sent to those interested, on request.

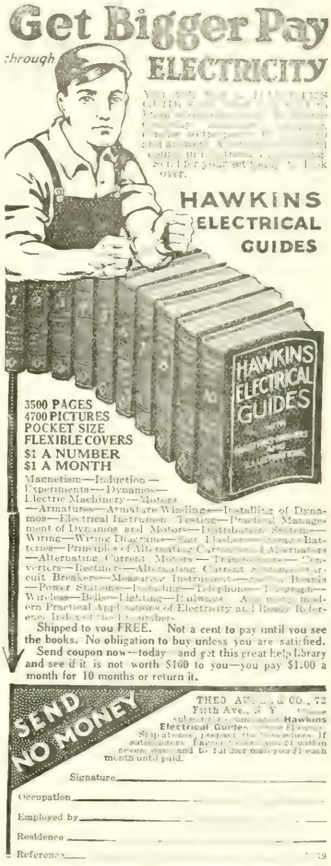
NEW NORMA FACTORY

—On December 10th the Norma—Company of America, manufacturers of "NORMA" Precision Bearings, moved its factory from the Bronx, New York City, to Anable Ave., Long Island City, N. Y. where a modern four-story reinforced concrete building has been acquired. Under the new arrangement a largely increased factory space is secured, making possible increased output of "NORMA" Bearings necessitated by the growing demand for these high-precision units. The new plant is being rapidly equipped with the special machines needed for precision manufacture, and the full capacity will be available shortly. The executive offices at 1790 Broadway have been consolidated with the factory at the new address.

NEW BOOKS

Dyke's Automobile And Gasoline Encyclopedia — 10th edition. 940 pages 532 charts and inserts. Published by A. L. Dyke, St. Louis, Mo. Price $5.00

An unabridged dictionary is about as easy to review as this automibile manual. If there are any details regarding automobiles and their operation omitted, it would be difficult to locate them. A casual checking with the previous edition might indicate that very little change has been made. However, while the page numbers have been kept the same, it will be found that numerous modifications have been made and additional material included by using more condensed type. The entire material is written in a clear and simple form with very thorough detailed illustrations. New sections are given on tractors, on airplanes and engines, on the Liberty engine and motorcycles. Detailed descriptions are given of the Liberty engine. Various other airplane engines are also shown and described.—



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NATIONAL SAFETY SECTION

The Electric Journal is pleased to announce the consummation of an arrangement with the National Safety Council whereby that organization will conduct a special safety department for the JOURNAL starting in the present issue. Through this arrangement the JOURNAL will be enabled to publish in each issue a special article on some phase of safety or its allied subjects under the general field of Industrial Relations. The National Safety Council also has undertaken to answer for the readers of the JOURNAL questions regarding safety work, sanitation, industrial hygiene and other phases of Industrial Relations. Inquiries to the Safety Section Question and Answer Department must be typewritten and should be stated as clearly and as concisely as possible. A stamped return envelope should be enclosed.

This arrangement makes available to the readers of the JOURNAL the valuable service of the National Safety Council—the nation's clearing house for information on statistics, methods, and experiences in accident prevention, sanitation and all phases of industrial relations. Inasmuch as the National Safety Council is a non-commercial co-operative association of some four thousand of the country's largest industrial concerns, governmental agencies, technical schools, etc., membership includes the great bulk of the safety engineering knowledge and talent of the United States.

During the next twelve months, the JOURNAL will publish articles prepared by the National Safety Council on a variety of subjects of particular interest to engineering readers.

LOUIS RESNICK
NATIONAL SAFETY COUNCIL

Like many other of the country's greatest institutions, the National Safety Council is the child of necessity. It is an organization that grew out of a great need, felt by the managers of industrial plants who were doing pioneer accident prevention work during 1912 and the half dozen years immediately preceding it—the need for a exchange of experiences in this work. No sooner had a few companies demonstrated what remarkable reductions could be made in accidents and what a great economic gain was yielded by accident prevention work, than other companies all over the country became interested and began to burden the pioneers in safety with inquiries for information regarding their experience. So great was the demand for information of this sort that the idea of forming a national clearing house for accident prevention information suggested itself to a group of some two dozen men who were in charge of safety work in as many plants.

This idea was crystalized at the annual meeting of the Association of Iron & Steel Electrical Engineers held at Milwaukee, Wisconsin September 30 to October 5, 1912 on which occasion that Association had provided for the discussion of safety at several sessions of the convention.

The National Council for Industrial Safety as it was then called, was officially organized at the Second Safety Congress held in New York City, September 23 to 25, 1913 with the following executive committee:—Messrs. R. C. Richards, C. & N. W. Railway Co., C. L. Close, U. S. Steel Corporation; David Van Schaack, Aetna Life Insurance Co.; Fred C. Schwedtman, Racine-Sattley Co.; L. R. Palmer, Chief Factory Inspector State of Pennsylvania; H. M. Wilson, U. S. Gov. Mining Bureau; C. W. Price, Ass't to Wisconsin Industrial Comm; Edwin R. Wright, Chicago; E. G. Trimble, Employers Indemnity Exchange; G. L. Avery Co., Charles Piez, Link-Belt Co., A. T. Morey, Commonwealth Steel Co., R. J. Young, Illinois Steel Co., R. W. Campbell, Illinois Steel Co., W. H. Cameron, Chicago.

The purposes of the organization as outlined by R. W. Campbell, the first president, follow:—

The National Council for Industrial Safety proposes "to promote the conservation of human life and its incidents in the industries of the nation, and to that end:

"(a) To establish a conveniently located headquarters for the maintenance of a clearing house of safety information, available to all concerned.

"(b) To encourage and promote throughout the country the organization of those engaged or interested in safety work into District and Local Councils, in affiliation with this National Council.

"(c) To hold annual congresses, at which all persons interested in accident prevention and kindred subjects may take part in practical discussion of vital problems, and also have opportunity to examine carefully prepared exhibits; to publish and give wide distribution to proceedings of such congresses.

"(d) To encourage and assist in the practical standardization of safety devices, safe conditions and practices.

"e) To give the widest publicity, through its own publications and other channels, to all matters calculated to promote industrial safety.

"(f) In general to initiate, promote, co-operate with and obtain the assistance of, any and all activities or agencies calculated to conserve human life and its incidents in the Nation's industries; and to participate in and aid other activities for the welfare of the industrial workers of the country."

It should be noticed that while the roster of the National Safety Council has grown from a promise of fourteen memberships in 1912 to approximately 4 000 industrial concerns operating more than 15 000 plants and employing more than 6 000 000 workers in 1919 and, while the scope and service of the Council have gone far beyond the bounds of the orginal plans, the purposes of the Council as outlined by its first president are substantially the purposes of the Council today, and almost every member of the orginal executive committee is on the much larger executive committee of today and very active in the affairs of the Council.

Within a few weeks after the opening of the headquarters in Chicago the general manager, Mr. W. H. Cameron through his contact with employers realized the need of a definite weekly service to members which resulted in the development of the now extensive bulletin service of the Council. Three bulletins suitable for posting on bulletin boards, where the messages of care and caution may come directly under the notice of the workmen, are sent to every member of the Council each week. In addition, bulletins showing specific hazards in special industries and methods of eliminating or reducing them are sent each week to the members of the Council in the respective industries dealt with by such sectional bulletins. For a number of years the Council also has sent each week a special bulletin for executives bringing to their attention the latest and best plans, methods and ideas for the prevention of accidents as demonstrated by the experiences of other members of the Council. Recently this executive series bulletin has envolved into a four-page weekly publication, the "National Safety News" through which the executive officers and the men in charge of safety in the plants of members of the Council are informed from week to week of the very latest developments throughout the world in the work of accident prevention and all other related subjects coming under the head of industrial relations.

In the latter part of 1916, the Council began to supplement its weekly bulletin service by monthly safe practices pamphlets, in each of which a particular hazard was discussed in detail and the safe practices in the construction and operation of the particular equipment involved were described . This phase of the Council's service has been developed to the point where each safe practices pamphlet represents the result of extensive research work on the part of a high grade safety engineer and the co-operation of a conference committee of seventy-five of the country's most eminent safety engineers in the enunciation of the safe practices observed in plants that have made the greatest progress in safety. It is safe to say that the safe practices pamphlets of the National Safety Council now represent the most concise and yet most comprehensive publication of the various subjects discussed in these phamphlets. During the last year or two the Council has also begun the practice of issuing sectional safe practices pamphlets in addition to those sent to the entire membership.

THE ELECTRIC JOURNAL

VOL. XVII FEBRUARY, 1920 NO. 2

The Function of Regeneration

The term "regeneration", as applied to a method of retarding trains when descending grades, is unfortunate in that it surrounds this important feature of railroad operation with an air of mystery. Getting trains down grades safely has caused much more concern than hauling them up grade. For this reason any system of holding trains which will relieve the air brakes of their heavy duty, thereby adding another factor of safety, is of great importance.

Regeneration by electric locomotives simply means that the weight of the train being propelled down the grade by gravity, becomes a source of mechanical energy, which is transformed by the motors into electrical energy, and is returned to the trolley wire to be used in the same manner as that from the power house.

The value of regeneration lies in the additional safety which it introduces to heavy grade operation, rather than to any monetary value of the electrical power produced. The wear and tear which is removed from the braking apparatus and rigging in descending long grades, insures their being in good condition for emergency use, and in stopping trains. The engineer is also assured of a fully charged train line for emergency stops on grades. The amount of energy obtained by regeneration is a function of the load and grade, and is only a small percent of that used in taking the train up a similar grade. In ascending a grade, power must be supplied to overcome transmission and locomotive losses, the friction of the train, the grade resistance and the resistance of the curves; while in descending, the only available power is that of gravity acting on the load, which in turn must overcome the resistance of the curves, the resistance of the train and the losses of the locomotive and transmission before any electrical energy can be utilized. If a train is descending a grade under regeneration, and the trolley circuit is opened or interrupted, it will at once lose its load, and the engineer then brakes the train with the air brakes in the usual way.

The axle generator regenerating system, as described in this issue by Mr. Ferris, has a valuable feature in that these generators, like the lighting generators on Pullman cars, obtain their mechanical power from the moving train, and this is used, not only to control the regeneration, but also to operate the air compressor motors, thereby insuring a constant supply of air, irrespective of the power received from the trolley wire. This will enable the engineer to proceed to the foot of long grades with the usual air brake operation, even though he should lose his power of electric regeneration entirely.

W. R. STINEMETZ

Enlarging the Field for Remote Control

The opportunities for effecting economies by the application of remote control to switching equipments are apparently limitless, especially where the operations are frequent and require close observation. On some of the usual applications, such as cranes, elevators, rolling mills and power station switchboards, the advantages in quick manipulation and safety are obvious. Multiple-unit railway equipments are a highly developed form of remote control, the fundamental requirement being, in addition to the other considerations, the need for simultaneous operation of several units. On all such applications, the great advantage is to locate the operator suitably for proper observation, and in the case of moving equipment, he usually rides on the vehicle.

The installation described by Mr. H. H. Johnston in this issue is unique in that it involves the remote control of both power and brakes on a locomotive with a 12-car train, and includes direct, as well as remote operation. In the case of the remote control, the operator does not ride with the locomotive, but operates from a tower located at the point where the individual cars are to be "spotted". The spotting problem has always been a real one in railway operation, particularly in switching service, and a great saving has been effected in this instance by locating the operator in the tower.

The successful working of such an installation opens up the field for tower control of one or more vehicles, so located as to be within the sight of a single operator. Wherever there is any great frequency of operation and the moves are of a uniform nature, such an equipment involves no great complications and is decidedly superior to the individual operation of units by separate operators. The track interlocking could be so combined with the tower control supply that not only could one operator govern the movement of a large number of vehicles, but the hazard of mistakes would be practically eliminated.

Undoubtedly, there are many other instances where a great quantity of material is handled within a small space and where the other conditions are such that similar installations could be used to advantage. One of the basic arguments for steam railroad electrification is the possibility of handling increased traffic over existing tracks, by taking advantage of the simplified control of train movements, and of the higher speeds which are thus made possible. The same advantages may make electrification worth while on steam shovels and similar installations, even when the actual power economies are not apparent. Electrification is not complete unless full advantage is taken of the possibilities of remote control.

L. G. RILEY

A Tribute to Albert Schmid

Charles A. Terry
Vice-President,
Westinghouse Electric & Mfg. Company

ALBERT SCHMID was born in 1857 in Zurich, Switzerland, where he also received his technical education. While in the employ of the French Westinghouse Air Brake Company he was personally selected by Mr. Westinghouse in 1885 for employment in the Westinghouse Air Brake Company, then located in Allegheny, Pa. When the Union Switch & Signal Company began its line of electrical development, Mr. Schmid was employed as chief designer and engineer. Later on, at the formation of the Westinghouse Electric Company in 1886, he was chosen to co-operate with the electrical engineers of that company in working out the mechanical designs. He was the chief engineer and later the shop manager of the Westinghouse Electric Company until 1897, when he made a tour of Europe for the purpose of studying manufacturing possibilities. As the outcome of this investigation, the Societe Anonyme Westinghouse was formed, and Mr. Schmid was made its director general. This position he occupied for many years and then was placed in general charge of the Westinghouse incandescent lamp interests in Europe, which position he occupied until his death, which occurred at the Hotel St. Hubert, New York City, on December 31st, 1919. (Ed.)

When the Westinghouse Electric Company was founded in 1886, for the immediate purpose of developing and exploiting the alternating-current system of electrical distribution, the most valuable asset of its organization was its personelle. Aside from that of the founder of the Company, three names are prominently associated and interwoven with its earlier history; these are William Stanley, Oliver B. Shallenberger and Albert Schmid. Mr. Shallenberger died in 1898, Mr. Stanley in 1916, and now upon the last day of the year 1919, the end has come to the earthly life of Albert Schmid.

ALBERT SCHMID

The first two of these associates were primarily electrical engineers, while Mr. Schmid was, by training and experience, a mechanical engineer. This designation, however, is scarcely adequate, for combined with his skill as a mechanical designer, was an artistic sense, which enabled him to impart to the machinery with which he dealt, a symmetry of form and beauty of line unequalled at the time and never surpassed in more modern apparatus. The designs which he early introduced into the electrical art, because of their great merit and attractiveness, have persisted through more than thirty years of progress, and are still reflected in various other classes of machinery.

At the time when Mr. Schmid became connected with the electrical industry, direct-current electrical apparatus had been developed to a considerable extent, and was being used for the distribution of central-station electrical energy through limited areas, but the alternating system was in use in this country not at all, and in foreign countries only to a very limited extent. Mr. Westinghouse had acquired the United States rights to the Gaulard and Gibbs transformer system, having a firm conviction that in it lay the solution of long distance electrical distribution, and it was this belief which led him to organize the electrical company which bears his name. The fact that Mr. Schmid was available to design and construct the mechanical portions of the apparatus planned by the electrical engineers, doubtless added greatly to his confidence in the successful outcome of the undertaking, and the skill and ingenuity which Mr. Schmid at once brought to bear upon the task thus placed upon him, justly won the enthusiastic confidence of his co-workers and the admiration of all others qualified to appreciate his work.

Simplicity of form was perhaps the most striking characteristic of his designs. A friend once asked Mr. Schmid how it came about that he was able to give to mechanical apparatus such graceful flowing lines, such artistic beauty, and received the modest answer "Why, all you have to do is to place the metal where it belongs and the machine becomes beautiful of itself". And here it may well be said that modesty was one of the great charms of Mr. Schmid's character. He never exhibited the pride he might justly have felt concerning his productions, however deep may have been the personal satisfaction with which he viewed them. His attitude was rather that of a man who, having faithfully studied and successfully solved the problems set before him, felt that he had merely honestly performed an expected duty.

Being of a studious disposition and possessed of a quick perception and an analytical mind, Mr. Schmid, through constant contact with the engineers of the Company, trained in electrical science, soon became well qualified in that branch of the art himself, as is well evidenced by the many useful electrical inventions which he made. The same qualities of mind which enabled him to sense and appreciate correct proportions and form in mechanical structures, enabled him almost intuitively to form correct judgments as to the proper proportioning and placement of the copper and iron, the active elements of the electrical machinery which it was incumbent upon him to produce. While he relied upon the technical electrical engineers to make the calculations involved in determining resistances, reactances and like factors involved, he was fertile and effective in his suggestions as to how the parts could best be disposed and interrelated for producing effective, durable and, at the same time, artistic machines.

Among the many inventions which he contributed to the alternating-current field, perhaps one of the simplest and at the same time daringly novel ones was that of building up the magnetic portions of the apparatus from sheets of soft steel, insulated from one another merely by surface films of oxide. Prior to this the sheets or plates had been interleaved with pasted paper, for the purpose of suppressing Foucault currents. The use of paste and paper in such mechanical structures jarred upon Mr. Schmid's sense of fitness and he therefore proposed to test the effect of omitting the paper and relying upon the thin surface oxides to afford the necessary insulation. While this seemed contrary to the theoretical conclusions of others, he insisted that it be tried and, accordingly, a small transformer was built in that fashion. All previous doubts of his fellow workers were set at rest by the complete success of the trial. The importance of this seemingly slight change in structure was of very large practical value in that it not only materially lessened the cost of building the generators, motors and transformers, but considerably reduced their size.

When the Company entered upon the electrical railway business Mr. Schmid, exhibiting his customary zeal and enthusiasm, promptly designed and developed railway motors which the purchasing public recognized as superior to any theretofore upon the market. In a very large measure the immediate success of the Westinghouse Company's street railway business was due to the sound judgment and skill exercised by Mr. Schmid in the design and construction of these railway motors.

Reviewing today the history of the development of the electrical industry, one significant feature which strikingly presents itself is the fact that among the many able and successful engineers who contributed to its rapid growth, there was but one notable mechanical engineer and that one was Albert Schmid.

There was another quality of Mr. Schmid's character which all who served with and under him admired and respected; it was his personal interest in their welfare and progress. With care he watched the development and studied the mental processes of the young men who came from schools and colleges to begin their life work in the Company's shops. Quick to reprove transgressions from orderly procedure, he was equally ready to commend, assist and advise those who showed an earnest, intelligent desire to learn and to progress. His influence upon these young men was always inspiring and the example he set of the manly way to treat young men and aspiring students is reflected in the actions of his successors in the Company, just as the artistic touch which he gave to the designs of its mechanical apparatus, persists in its present products. Both of these influences will long remain a worthy tribute to the memory of Albert Schmid.

The Power Indicating and Limiting Apparatus

For the Chicago, Milwaukee & St. Paul Railroad

B. H. Smith

IN THE UNITED STATES, the railroads are our largest users of power. It is stated that locomotives burn 25 percent of the coal from our mines, and that 12 percent of all freight hauled is coal for railroad users. As certain sections become electrified, the requirements for coal and coal handling disappear, but the supply and regulation of the large amounts of electrical power required become a serious problem. In several cases, the railroad companies have built their own electrical power systems, but when possible, it is usually more satisfactory to make use of existing central stations. The difficulties attendant on the addition of a large railway load to a central station are greatly reduced if the added load is reasonably steady, less generating equipment being required and the interference with voltage regulation to other customers minimized. The Chicago, Milwaukee & St. Paul Railroad, on its latest electrification from Tacoma and Seattle, for a distance of 200 miles east over the Coast and Columbia Divisions, decided to centralize the control of the road, and obtain an indication at one point, the office of the chief dispatcher, of the total power taken by the road, and to regulate this power so as to keep the peaks below a certain definite limit.

The centralizing of this indicating and control system required some means of transmitting the indication of meters in the various substations to the dispatcher's office. There are four main stations where power is received into the railroad transmission system from its respective sources and metered. There are, in addition, four intermediate stations supplied from the transmission circuit which require no metering of power received. The regulation of power is accomplished on the direct-current side of the substations, and therefore all eight substations must be controlled in this respect by the circuit from the dispatcher's office. This problem arose several years ago in connection with the electrification of this same railroad over the Rocky Mountain section. The problem was solved in that instance by the expedient of introducing a resistance into a pilot wire system at each station where load was to be measured, the amount of such resistance to be proportional to the load. Then the current flowing in the pilot wire became inversely proportionl to the power in the whole system. The method is open to the objection of current leakage, especially in wet or foggy weather. Moreover, the copper pilot line is subject to considerable change in resistance, due to changes in temperature, and it was necessary to make provision for checking and adjusting this part of the system periodically to the proper values.

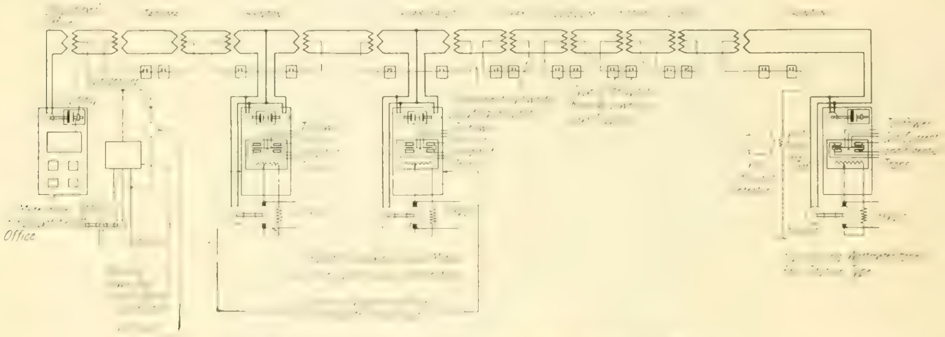

FIG. 1 DIAGRAM OF POWER INDICATING AND LIMITING SYSTEM

On the Coast division, which is subject to much dampness and wet weather, it was felt that some other method of transmitting the meter indications was necessary, and it was proposed to use frequency as a means of solving the problem. Various methods of tying together the eight stations were considered, but the arrangement here described seemed the most desirable and was adopted. A one kilowatt generator at Taunton, the first station on the east end of the electrified section, generates a current, whose frequency is so controlled that it varies with the power as measured by the wattmeter in the Taunton substation. The voltage generated is stepped up to 2000 volts and transmitted to Cedar Falls about 100 miles away. Here the frequency is not increased directly, but another alternating-current generator is introduced, and so controlled that its speed and frequency are proportional to the power being measured at Cedar Falls, plus the power indicated from Taunton. This second frequency is transmitted on to Renton, and the process is repeated. From Renton, the frequency goes to the dispatcher's office near Tacoma, where it indicates the total of all the power received by the electrified section of railroad. In the future, there may be power incoming at the Tacoma substation, and if desired, this station can be connected in series with the other three.

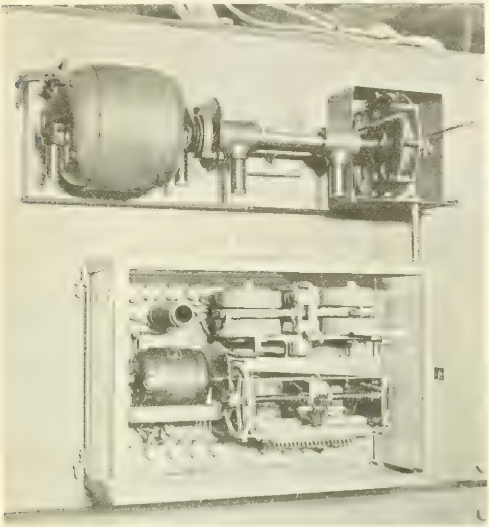

FIG. 2—EQUALIZING METER AT TAUNTON

In order to make use of frequency as a reliable indicator of power, it was required that it should be capable of measurement over a large range with great accuracy, and with a device having considerable power. For this purpose, the ordinary frequency meter is not suitable. Small synchronous motors, however, were available, and these could be coupled to magnetos, thus giving a direct-current voltage proportional to the frequency, which voltage could readily be arranged to perform the proper functions. This method would probably have been used, but the magneto is a little too heavy for the small synchronous motors, and moreover would require considerable attention. The speedometer principle of revolving magnet acting on an aluminum disc by induction was proposed, and experimental models showed such high torque, accuracy and apparent freedom from upkeep difficulties that this method was adopted. Moreover, the mechanical power required at this point would never exceed five watts.

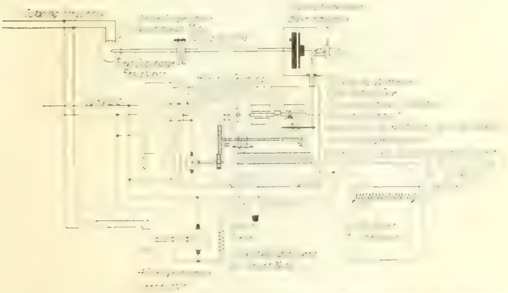

FIG. 3—EXTERNAL CONNECTIONS OF THE EQUALIZING WATTMETER AT TAUNTON

The system as finally laid out is shown diagrammatically in Fig. 1. At Taunton, the first station, the power is measured by a contact-making wattmeter of the Kelvin balance type shown in Fig. 2. This meter controls a small motor which operates a slide resistance in the field of the one kilowatt motor-generator set, as shown in Fig. 3, whereby the frequency can be varied from about 25 to 60 cycles. If the wattmeter were at zero load, we should expect to obtain zero frequency. It is manifestly impossible to operate a synchronous motor under such conditions, hence a spring tension is introduced, which gives a torque proportional to 25 cycles, which was the value selected as the "base frequency". The spring holds the lower contact of the wattmeter closed until the automatic slide resistance brings the motor-generator set to the 25 cycle speed, and with it the small synchronous motor with its revolving magnet. At this speed, the magnet exerts just enough torque on its disc to balance the spring torque, and the contacts are held in the neutral position; thus as long as there is no load on the wattmeter, a steady frequency of 25 cycles is transmitted through the whole measuring circuit, and this quantity must be subtracted at the end of the line in the dispatcher's office in getting the total load indication. As soon as Taunton begins to supply power, the wattmeter experts an additional torque, making contacts which operate to increase the resistance in the motor

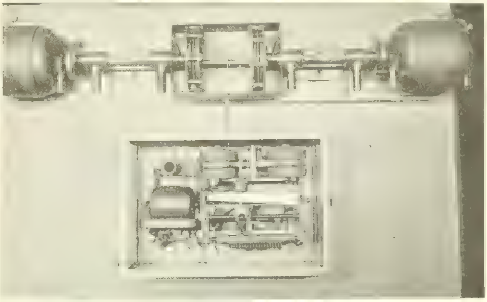

FIG. 4—EQUALIZING WATTMETER AND SYNCHRONOUS MOTORS AT AN INTERMEDIATE STATION

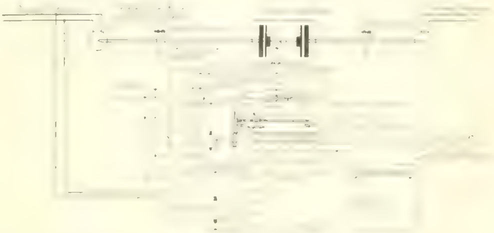

FIG. 5—EXTERNAL CONNECTIONS OF EQUALIZING WATTMETER AT AN INTERMEDIATE STATION

field circuit of the motor-generator set, and the frequency increases until the increased speed of the synchronous motor just balances the torque of the wattmeter, and thus, if the incoming power corresponds to, say, 10 cycles, 35 cycles is sent out over the circuit.

When a number of trains are running down grade, the locomotives regenerate, and energy is delivered back into the power lines through the substation. This causes the wattmeter to oppose the spring action, the speed of the motor-generator set is decreased, and something less than 25 cycles is sent out.

At the next station, Cedar Falls, the incoming frequency from Taunton operates a receiving synchronous motor with a revolving magnet similar to the one at Taunton. There is also provided a sending synchronous motor, as shown in Fig. 4. The two aluminum discs are mounted on the same shaft and operate differentially, that is the speed of the motor-generator set is automatically adjusted by the slide wire resistance until the difference between the torques exerted on the two discs is exactly balanced by the wattmeter action. As the torque of the receiving motor, even during regeneration, is never less than that due to approximately 20 cycles, no spring is needed on the wattmeter. Otherwise, the wattmeter, slide resistance, and motor-generator set, as shown in Fig. 5, are similar to the apparatus at Taunton. Assume 35 cycles incoming, the speedometer torque is added to the wattmeter torque, and the motor-generator set speed is controlled until there is perhaps a frequency of 40 cycles outgoing. This outgoing frequency is transmitted to the next station, Renton, where the apparatus is similar to that at Cedar Falls, and the frequency is there still further increased in proportion to the load on this station. At the last station, Tacoma, there will be a final increase when this station is in service, and thence the circuit proceeds to the dispatcher's office. The frequency is now equivalent to the total power used, plus 25 cycles.

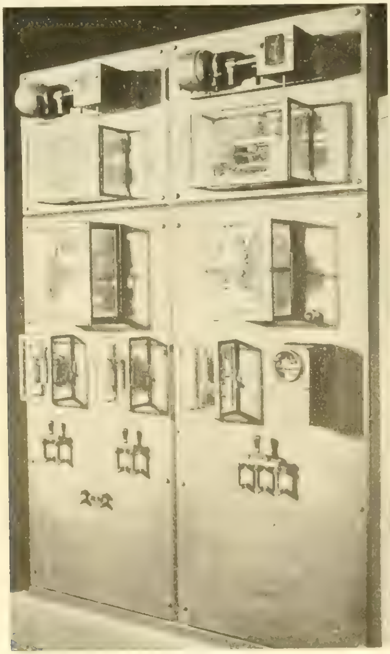

FIG. 6—POWER INDICATING AND LIMITING BOARD AT THE DISPATCHER'S STATION

Left panel—synchronous motor, equalizing wattmeter, type M graphic wattmeter and contact making auxiliary relays controlled by the load regulator.

Right panel—synchronous motor, equalizing wattmeter, type RA demand wattmeter, type RO load regulator and auxiliary relay controlled by the demand wattmeter.

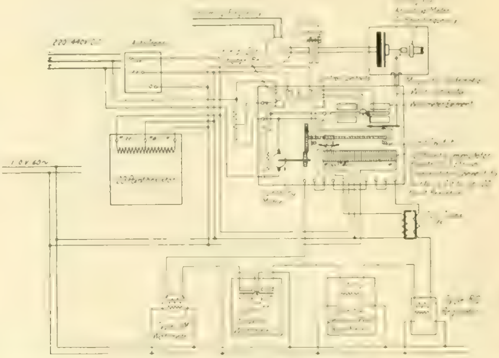

FIG. 7—EXTERNAL CONNECTIONS OF EQUALIZILNG WATTMETER AT THE LOAD DISPATCHER'S STATION

At the dispatcher's office, Fig. 6, there is a synchronous motor speedometer as at the power stations, and its torque is balanced with a wattmeter. A spring similar to the one at Taunton opposes the speedometer torque. Hence, the wattmeter must balance only the frequency due to actual power consumed. This wattmeter is supplied by a local 60 cycle circuit, as shown in Fig. 7, and the watts are controlled by the automatic slide. As the incoming frequency changes,

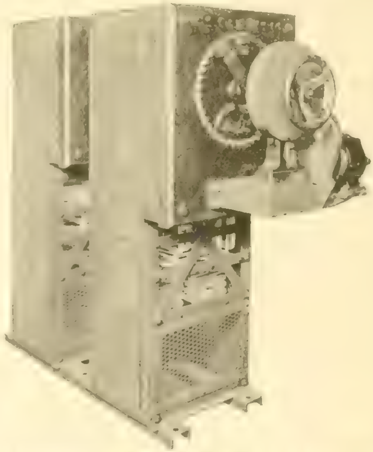

FIG. 8—MOTOR OPERATED GENERATOR F. I. & L. RHEOSTAT

the wattmeter contacts cause the slide to move, and maintain in the wattmeter circuit the proper value of watts, equivalent to the total power. This circuit is also connected to an indicating wattmeter, a graphic recording wattmeter, a graphic demand meter, and a time lag type load regulator.

Since the railroad buys this power on the basis of a maximum five minute integrated load, it is advantageous from a commercial as well as an operating standpoint, to keep the peak loads as low as possible. This is accomplished through the agency of the load regulator. When the load approaches a predetermined point, this regulator closes its contacts in the lowering direction and sends out over the signaling circuit a direct current which operates a polarized relay in each substation. The signaling circuit consists of the same wires that carry the frequency indications. The direct current is fed into the middle point of the high-tension winding of the transformers, and as it divides equally in the two halves of the winding, it has no effect on the magnetic circuit. The two wires in parallel thus form a "phantom" or derived circuit, as shown in Fig. 1, the return circuit being through the ground from Taunton back to the load dispatcher's office.

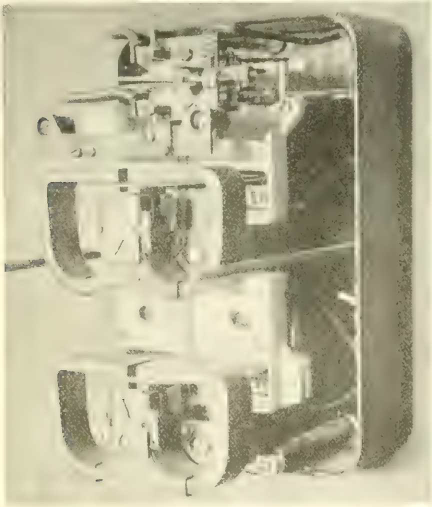

FIG. 9—TYPE RO LOAD REGULATOR

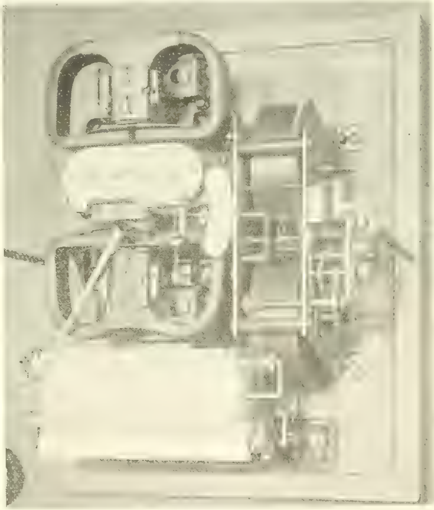

FIG. 10—TYPE RA DEMAND METER

Indicating and recording five minute maximum demands and provided with contacts which serve to trip all the circuit breakers on the system if the five minute demand exceeds the setting of the pointer.

The generator field circuits in each substation are provided with a motor-operated rheostat, Fig. 8, in addition to the usual field rheostat, whose function is solely to reduce the voltage of the generators which supply power to the 3000 volt trolley at times of heavy overload. These rheostats are controlled by inverse time element overload relays, which are normally set to reduce the voltage at 300 percent of rated load. The operation of the polarized relays, when they are actuated by the current from the phantom circuit, is to change the setting of the inverse time element relays to 50 percent of rated load, so that the action of the direct current in the phantom circuit is to reduce the voltage on all generators carrying more than 50 percent of rated load, and because of the inverse time element feature, the generators which are most heavily loaded are affected first. It may thus readily happen that reducing the voltage at only one substation will reduce the load sufficiently on the entire system.

In a few seconds the reduced load has its effect on the regulating meter back in the dispatcher's office. Its contacts open, and the stations continue to run at the reduced voltage until the load becomes low enough to cause the regulating meter to close its other pair of contacts. When this happens, a direct-current is sent out over the system in the opposite direction, operations are reversed, and the voltage is raised. The regulation is adjusted as high as possible without exceeding the five minute demand previously agreed upon, but it is quite likely that, in case of a sudden heavy load coming on the railroad, the five minute demand limit would be too closely approached. To provide against such an event the recording demand meter is fitted with a contact circuit which closes the direct-current phantom circuit through a reduced resistance, sending out about four times the current through the line that is used for reducing the voltage. This increased current operates a second set of polarized relays in each substation, which trip the circuit breakers in all the stations.

There are many interesting features connected with the whole system, not the least of which is the line itself. No. 8 copper wire is used, and there are only two wires. The frequency circuit is stepped up, between stations, by means of ordinary 100 to 2000 volt distributing transformers. There are taps at the middle points of the high tension windings which are used for the phantom, or derived, direct-current circuit. In the four main stations, there are two transformers, one incoming and one outgoing, but at the four intermediate stations, only one is required, the ratio being 2000 to 2000, with middle point taps for the direct-current circuit. If, by accident or otherwise, any station should be out of service, the synchronous motors are disconnected automatically, and the transformers are connected together on their low-tension sides; thus the frequency indication is carried on to the next station. This is accomplished by a relay switch, held in normal position by the direct-current supply circuit.

The direct current for raising and lowering the voltage, and for circuit breaker tripping is obtained from a 440 volt direct-current supply circuit in the dispatcher's office. Since the direct-current line is really the two No. 8 copper wires in parallel, and since the polarized relays are of low resistance, and operate on small current, this value of voltage is ample. The increase in current required to give the tripping impulse is obtained simply by short-circuiting a resistance in series with the line.

In case of a ground on the signaling line, there is an unbalance of the phantom circuit, and this circuit receives a considerable alternating-current potential above ground. Also, a small alternating-current flows through the polarized relays, and is likely to render them temporarily inoperative. There is no interference, however, with the transmission of the frequency indication, unless the ground develops into a short-circuit, in which case, of course, the indication could not be transmitted beyond the short-circuit. The alternating-current potential of the phantom circuit furnishes a ready means of indicating and locating grounds. It is only necessary to connect a voltmeter from the line to ground at suitable points, and these will immediately show a reading when a ground occurs, even of exceedingly high resistance. In the actual installation, there is a voltmeter in the dispatcher's office, and one at Taunton. In the dispatcher's office, it is necessary to interpose a condenser between the voltmeter and ground so as not to short-circuit the direct-current raising and lowering impulses. At Taunton, the phantom circuit leads to ground after going through the polarized relays, and for the ground detector it is only necessary to interpose a transformer in series with the line, the voltmeter being connected to its secondary.

Much of the equipment used for the system is standard or semi-standard apparatus, but in some cases, special development was required. It was found that synchronous motors for the frequency measuring outfits would not readily pull into step on account of the added inertia of the revolving magnet, although when once in step, there was ample power to change speed quickly and rotate at the maximum r.p.m. desired. A polyphase connection was found to improve the situation materially, but this would entail undesirable complications. The final solution was found in placing a spring drive between the motor and the magnet, the magnet having a separate shaft and bearings. The spring allows the motors to make the necessary quick acceleration at the moment of coming into synchronism.

It might be questioned whether the lowering of voltage at intervals would hamper the movement of trains. It is true that (with any control of peak) there is a certain slowing up of train speed at these times. The handicap resulting therefrom is obviously offset by the improved condition of use of power. The improvement in load factor due to this regulation may well be considerable and is that reached by the best compromise between reduction of speed at such times and such burden as may be imposed on the supply of power to carry load under conditions of peak demand.

The Axle-Generator Regenerating System

Used on the Chicago, Milwaukee & St. Paul Passenger Locomotives

R. F. Ferris

THE Chicago, Milwaukee & St. Paul Railroad passenger locomotives are equipped with a regenerative system which may be called, for lack of a better name, an "axle-generator system". After numerous trials of various systems, both on test and in actual service, this system was adopted because it has, for the service in question, almost ideal characteristics.

In any system involving regeneration, the following points are all desirable and some are absolutely essential to the successful operation of the system:—

1—Safety for vehicle, (locomotive or car).
2—Protection to electrical apparatus, such as motors, auxiliary rotating apparatus, switches, etc., from voltage surges and current overloads.
3—Efficiency
4—Simplicity

These points are not necessarily in the order of their merit; nor do they cover all the factors.

For the safety of the vehicle, it is necessary to have a regenerative system of such a nature as to prevent the possibility of the engineer's losing control of the train on grades, as might be the case if the train gradually increases in speed while regenerating, thus almost imperceptibly reaching a speed where the air brakes would not be effective in bringing the train under control. The retarding tractive effort, therefore, must increase rapidly with the speed to protect the car or train.

To protect the motors and other apparatus from overvoltage surges or sudden drops in voltage due to short-circuits, or other trains starting while the locomotive is regenerating, the generated voltage of the main motors must rise and fall with the line voltage.

In the axle-generator regenerating system, the main motors are separately excited from an axle-generator, whose fields are separately excited in turn from a storage battery, or some other constant voltage source. The axle-generator is connected across the main motor fields with a balancing resistance in series, as shown in Fig. 1. The main motor armature current is carried through the balancing resistance R, thus giving a differential effect on the main motor fields when the regenerated current increases, due to a drop in line voltage. This differential effect is essential to stable operation of the main motors and, therefore, a more detailed explanation will be given.

In any closed circuit, the sum of the voltages is zero as, for example, in the case of the circuit from generator G_2 through resistance R and field F in Fig. 1. In other words, the voltage G_2 forces sufficient current through the circuit so that the IR drop just balances the voltage of generator G_2. If a current from some external source is drawn through resistance R, the voltage available for forcing current through the circuit G_2, R, F is decreased. The relation between field and regenerated current for a constant axle generator voltage is shown in Fig. 2. If, with the axle-generator system, the speed of the locomotive or car increases, the voltage of the axle-generator increases, thus raising the excitation on the main motor fields, increasing the main motor generated voltage, thus increasing the regenerated current which, in turn, raises the retarding tractive effort. It is evident that there will be no sudden change in locomotive speed, so the speed-ampere characteristic of the locomotive can be such as to give a large increase in retarding tractive effort with a small change in speed. However, a change in line voltage may be comparatively sudden, and for this reason the method of increasing or decreasing the generated voltage of the main motor should be rapid and certain. This is accomplished by the resistance R, Fig. 1, which is positive in its action, reducing the main motor field with any increase in armature current, or increasing the field with decreasing armature current, as before explained. Fig. 3 shows curves of "regenerated amperes" plotted against miles-per-hour, and retarding tractive effort for a given control notch, showing the large increase in retarding tractive effort with increase in speed. Fig. 4 shows how a comparatively large change in voltage may occur either up or down without dropping the load entirely or taking on an excess. From these characteristics, it is evident that, with the axle-generator system, two desirable, fundamental and apparently contradictory things are accomplished.

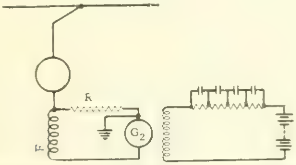

FIG 1—SCHEMATIC DIAGRAM OF AXLE REGENERATING SYSTEM

In any system of regeneration where the source of main motor field excitation during regeneration is derived from some line-driven apparatus, the auxiliary apparatus and main motors are subject to over-voltage conditions if the trolley should lose contact with the line, as in this case the main motor voltage immediately rises. This, in turn, raises the field excitation and causes the main motor generated voltage to rise yet farther. This cumulative effect acts very quickly and, if not checked by an overvoltage relay, is almost sure to cause some of the apparatus to flash. With the axle-generator, variations in line voltage have no effect on the excitation of the main motors, except by a change of load through the balancing resistance; and while the main motor voltage rises slightly when contact is lost with the line, the effect is not cumulative.

Two examples, the first for a change in speed, and the second for change in line voltage will, perhaps, explain the operation of the system more clearly. Assume that the locomotive is descending a grade and is regenerating a given current. If the grade increases, the locomotive and train will tend to speed up, but as the train speeds up, the axle-generator voltage will increase, which will tend to increase the main field. The increase in speed will, however, increase the regenerated current which, passing through the balancing resistance, tends to decrease the main field strength. These two tendencies, therefore, oppose each other and, on the changed speeds, will reach a new balanced condition.

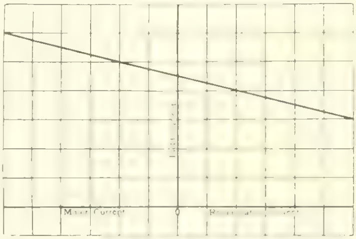

FIG 2—RELATION OF FIELD AND ARMATURE CURRENTS DURING REGENERATION

For the second example, assume a train on a grade regenerating a certain current. If the line voltage suddenly drops, the regenerated current increases, but this increase in current, acting through the balancing resistance without being even partly offset by increasing the voltage of the axle-generator, rapidly reduces the main motor field, and thus limits the current to a normal increase, unless the voltage drop is abnormal. Or, if the line voltage suddenly rises, the regenerated current decreases; but in turn this decrease permits the main field current to increase, thus limiting the reduction of regenerated current.

It may, perhaps, be interesting to give a mathematical expression for the axle-generator regenerative system. To do this, it will be necessary to make two assumptions, neither of which would change the general relation, but which introduce sufficient error to prevent the use of the expression, except in a qualitative way. The first assumption is that the field distortions of the main motor and of the axle-generator offset each other, which is only true to a certain extent. The second is that the main motor field current, divided by the main motor generated voltage, gives a straight line when plotted against the field current, which is approximately correct. With these assumptions, referring to Fig. 1:—

$$I_f = \frac{E_g - (R_b I_a)}{R_b + R_f} \qquad (1)$$

$$E_g = C_1 S \qquad (2)$$

$$E_m = \frac{C_2 I_f S}{C_3 + C_4 I_f} \qquad (3)$$

Equation *3* is the second assumption before stated, expressed algebraically also,—

$$E_m = E_e + I_a (R_b + R_m) + R_b I_f \qquad (4)$$

By substitution, solving for I_a and combining all values which are constant for a given system, the general relation is given as follows,—

$$I_a = \frac{C_5 I_f^2 - C_6 I_f - C_7}{C_8 - C_9 I_f} \qquad (5)$$

Where—

I_f = Current in main motor fields.
I_a = Regenerated amperes in main motor armature.

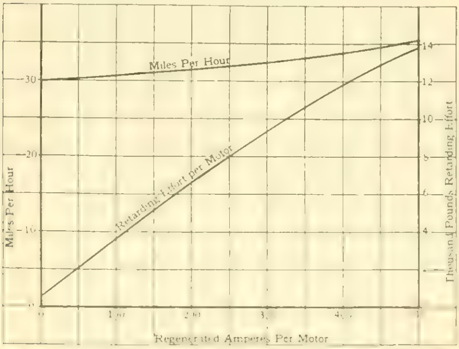

Fig. 3—Retarding Effort with Constant Line Voltage
1800 volts per motor; third speed combination.

E_g = Axle-generator volts.
E_m = Main motor generator volts.
E_e = Line volts.
R_b = Balancing resistance.
R_f = Main motor field resistance.
R_m = Main motor armature and commutating field resistance.
C_1, C_2, etc. = Constants.

As stated before, the Chicago, Milwaukee & St. Paul passenger locomotives are equipped with axle-generators and have, therefore, during regeneration, the foregoing characteristics. There are two axle-generators, one each on the front and rear pony trucks. The fields of these axle-generators are excited in series and are under the control of the engineer during regeneration by means of a motor-operated rheostat. The locomotives are equipped with six twin main motors arranged in the following speed combinations:—

1—All six motors in series.
2—Three motors in series; two in parallel.
3—Two motors in series; three in parallel.

During motoring, each combination has two shunt field positions. These field shunts, however, are not used during regeneration as the entire speed range is covered by means of separate excitation on the main motor fields from the axle-generators. During regeneration, the main motor armatures are arranged in the same combination as when motoring, but the fields are excited as follows:—

No. 3 combination—two fields (twin) in series, three in parallel.
No. 2 combination—three fields (twin) in series, two in parallel.
No. 1 combination—same as No. 2.

To obtain the same slope to the speed—regenerated amperes curves in all combinations, the *IR* drop in the balancing resistance for a given regenerated current per motor circuit should be the same percentage of the field *IR* drop for the same field amperes in each case; or for the same slope the value $\frac{R_b \times I_b}{R_f \times I_f}$ should be a constant for a given field and armature for all combinations, where I_b = the current in the balancing resistance.

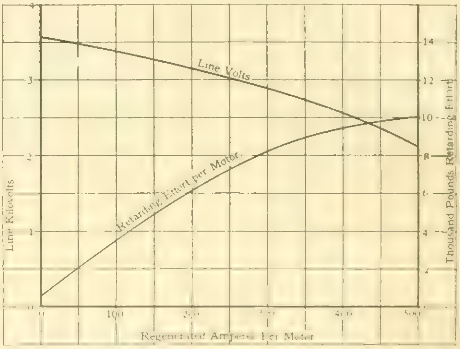

Fig. 4—Retarding Effort with Constant Speed
At 30 miles per hour; third speed combination.

For example, there are two twin fields in series in the No. *3* combination and three twin fields in series in the No. *2* combination. Therefore, with a given current in each case, the value R_b should be increased one-third for the No. *2* combination over that required for the No. *3* combination. However, in the No. *1* combination, the armature current divides between the two balancing resistances and the foregoing ratio will be smaller in the No. *1* combination than in the No. *2* or No. *3* combination, if the value R_b is not further increased. On the Chicago, Milwaukee & St. Paul locomotives, the value R_b is the same for the No. *1* and the No. *2* combinations. The slope of curve, therefore, is less in the No. *1* than in the No. *2*, or the No. *3* combination. This simplifies the control and is perfectly feasible, because the motors are all in series and stability is more easily obtained in this combination.

In service, the axle-generator system applied to locomotives has more than met expectations with respect to flexibility and stability of operation.

Remotely Controlled Electric Locomotives

In the By-Product Coke Industry

H. H. Johnston

IN KEEPING with other methods in use at modern byproduct coke plants, a recently completed plant has installed remotely controlled combination third rail and storage battery locomotives for handling coke bars while being loaded at the coke screening station. In a plant of this size, where the cars loaded in twenty-four hours are numbered by the hundred, in a constant and never ending stream, the methods employed required very careful consideration.

The cycle of operation consists of hauling eight empty cars from the empty car storage track and spotting the first car under the loading chutes at the screening station. The motorman then throws a switch that places the locomotive under the control of the operator in the screening station and leaves the locomotive. The operator then slowly moves the train forward, stopping or reversing it as conditions may require, thereby securing an evenly and completely loaded car. There are two operators on the screening station, each one being located in a cab midway between two tracks, and, in addition to controlling all conveyors and screen equipment on one-half the station, they control two locomotives at a time.

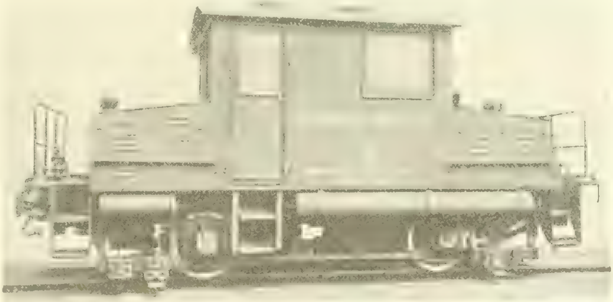

FIG. 1—36 TON REMOTELY CONTROLLED LOCOMOTIVE IN THE BY-PRODUCT COKE INDUSTRY

When the cars are loaded, the motorman returns to the locomotive and draws the cars to the classification yards, returns for empty cars and the cycle is completed. The services of but two men are required to handle the shifting for the entire station.

The use of the electric locomotives has eliminated smoke, underloaded cars, a large amount of labor and reduced the spillage at the loading chute. It was found practically impossible to load more than three cars at a time with steam locomotives, due to the inability to signal the engineer from loader's cab, on account of the steam arising from the hot coke.

The locomotives and their equipment were planned to have the following features:—

1—Remote control (controlled from tower).

2—Cab control (controlled from locomotive cab).

3—Use of a single control wire between tower and locomotive.

4—Operate from battery supply when the locomotive is out of the tower control zone and away from the power rails.

5—Operate from power rails when the locomotive is in tower control zone.

6—Battery automatically obtains its charge when locomotive is run from the power rails in the tower control zone.

7—Battery automatically supplies power to the motors, when locomotive is run out of tower control zone.

8—Cab control whether locomotive is in tower control zone or out of tower control zone and motors obtaining power from battery.

9—Provision for both straight air and automatic air brake operations.

10—Slow speed and short distance of train movements when the locomotive is under control of the tower operator.

11—Operation of two or more locomotives from any one of the locomotive cabs.

The electric locomotives used for this service weigh 36 tons and are of the combination battery—power rail type. The equipment consists of two—75 hp, 250 volt motors geared by double reduction (ratio 16:72 and 74:29) to driving axles with 33 inch wheels. Each locomotive is equipped with a 110 cell MVY-25 Exide battery; this being the largest battery ever applied to locomotive service. A control panel with necessary hand-operated knife switches, meters and fuses, is provided to permit control of the battery circuits. The battery normally has all cells in series for charge and discharge, automatically giving up its charge when the locomotive is operating out of the power rail or tower control zone, and automatically charging when operating in the power rail zone. Provision is made for giving the battery a gassing charge by connecting two halves of the battery in parallel and in series with a charging resistance across the power supply.

When the locomotive is operating in the loading zone, under the control of the tower operator, power is supplied to the motors and main control circuits, as well as the battery being charged, from power rails located one on each side of the track, coming into contact with current collectors of the under-running contact shoe type located on beams on each side of the locomotive. Directly under one power rail, a control rail is located which comes into contact with a current collector of the over-running contact shoe type. This control rail carries only small currents as required for the tower control circuits. This control rail with its lead wire to the tower constitutes the only direct electrical connection between the locomotive and the tower.

The control equipment in the locomotive is of the electropneumatic type, providing for series-parallel control of the main motors when operating the locomotive from the cab of the locomotive and series control only when operating from the tower. The scheme of the auxiliary control circuits in the case of tower and cab control is the same, and depends primarily upon energizing a single wire at a positive or negative potential, depending upon the direction of motion of the locomotive desired, whether forward or reverse. This wire is connected to a point common to two shunt relay coils connected in series across the line. The shunt relays are located in the locomotive. By making this common point have a definite potential relation with respect to the shunt coil connections to the line, either one of the relay coils may be de-energized, i.e., if coils *A* and *B* are in series across the line, coil *A* may be de-energized by giving the common point between *A* and *B* a positive potential, or coil *B* may be de-energized by giving the common point a negative potential. Arranging the relay discs to complete electrical circuits to reverser switches provides for obtaining forward and reverse operation of the locomotive.

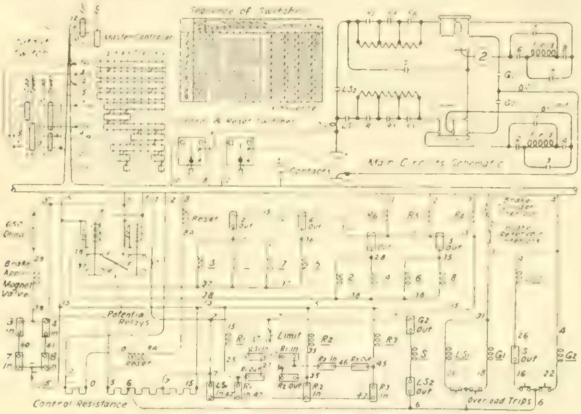

FIG. 2—SCHEMATIC DIAGRAM OF MAIN AND CONTROL CIRCUITS

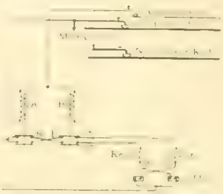

FIG. 3—SCHEME OF CONTROLLING RELAYS

The control wire to the forward and reverse switches becomes energized immediately upon the operation of the shunt relays, but neither the forward nor the reverse switches can be operated unless the reverse and forward switches respectively are out. Before the main accelerating switches can be operated the brake cylinder pressure must be reduced to zero and, as a safety feature, the brake reservoir pressure must be above a predetermined value.

When operating from the cab of the locomotive, the master controller is operated in the usual manner. Upon taking the locomotive into the tower control zone, the motorman brings the master controller to the off position and operates a cab-tower control change-over switch and then signals by whistle to the tower operator that he may take control of the locomotive and proceed with the loading of the cars.

When operating from the tower, the control rail is given either a positive or a negative potential at the tower by operating a simple drum type switch, which connects the lead from the control rail to either the positive or negative side of the power supply which also supplies power to the motors on the locomotive. As described above, the shunt relay coils are energized in the proper sequence to obtain forward or reverse operation of the locomotive and train. Immediately upon operating of the forward or reverse switches a circuit, through interlocks on these switches, is completed and energizes a brake valve magnet which controls the release of the brakes. Upon release of the brakes, the locomotive accelerates to a speed corresponding to the third resistor step, with the motors in series. This speed is approximately 0.5 mile per hour. A current limit relay is provided to give automatic acceleration up to this speed.

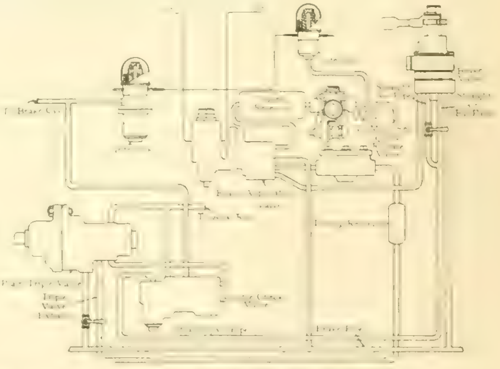

FIG. 4—DIAGRAM OF REMOTELY CONTROLLED ELECTRIC LOCOMOTIVE BRAKE EQUIPMENT

The air brake equipment is of the combined automatic and straight air type consisting of two 250 volt, direct-current motor driven air compressors; one governor; one brake valve; one triple valve; one double check valve; one electrically actuated brake application valve; one quick release valve; one feed valve; one timing reservoir; one cylinder interlock; one brake reservoir interlock, and other pneumatic details. With this equipment quick and flexible operation of the brakes is effected on the locomotive by straight air when operating singly or when switching, with the added facility of changing over to automatic operation when operating in trains.

As the train enters the zone in which the locomotive and train movements are to be controlled from the tower, the engineman may do one of two things in stopping and giving the control of the locomotive over to the tower operator:—Make a brake application by means of the brake valve and, when the train has stopped, place the cab-tower control change-over switch in the locomotive, in the "tower" position and then move the brake handle to the release position, after which the locomotive movements can be controlled from the tower or, 2—while running along with the brake valve handle in the release position, place the cab-tower control switch in the tower position, which de-energizes the brake application magnet and produces application of the brakes, after which the tower operator may control the locomotive and train while loading the coke into the cars. The function of the quick release valve in the air brake equipment listed above is to provide a quick release of the locomotive brakes when under tower control, so that successive movements desired can be accomplished quickly.

The control equipment on each locomotive provides for operating two or more locomotives in multiple by controlling from any one of the locomotive cabs or by controlling from the tower when the locomotives are operating in this zone. The service conditions require that the switch groups, and other control equipment be protected from coke dust and to accomplish this, dust tight covers are provided on each piece of apparatus.

The battery is assembled in two groups, one group being located under the hood on either end of the cab. Hinged covers permit opening the hood for inspection of the battery or permit swinging it out of the way to remove the battery from the compartment. Special safety switchman's steps, as shown in Fig. 2, are provided in order to reduce the danger to trainmen to a minimum. The auxiliary equipment consists of hand operated gong, air whistle, headlights, electric cab heaters and cab lighting.

This type of locomotive has exceeded all expectations in its service application and indications are that it will have a great number of applications in other industrial plants, factories and such open industries as surface mining and quarries.

Current Limit Acceleration for Electric Motors

H. D. James

EVER SINCE the electric motor came into use, the automatic short-circuiting of the starting resistance as a means of accelerating electric motors has engaged the attention of controller engineers. The smaller motors are easily started and require only one or two steps to accelerate them successfully. For such motors the counter e.m.f. system of acceleration is satisfactory and involves no complicated connections.

The earliest automatic means of acceleration used was a dashpot or other mechanical device which retarded the progress of the mechanism for short-circuiting the starting resistors. For many applications, this time element method is desirable, but dashpots have not proved entirely satisfactory and the pilot motor device is expensive for small controllers.

For heavy duty starters, particularly where the operation is frequent, the favorite method of acceleration is by using a current limit device which accelerates the motor at a constant current and therefore at approximately a constant torque. The most reliable current limit device consists of relays used in connection with shunt wound contactors. The shunt contactor exerts a positive closing action independent of the load, and remains closed even on reversal of current, which is not the case when a lockout contactor is used. The current limit relay adds a little to the initial cost of the controller but its operation is satisfactory and it can be readily adjusted within its range.

The current limit relay commonly used today is provided with a series coil. While this relay has a considerable range of adjustment, it is necessary to provide for a number of different series windings in order to apply the relay to the varying sizes of motor required for different drives. Some times a larger motor is secured than is actually required for the application, either because the proper size is not known or extra capacity is desired as a matter of insurance. This may lead to the use of relays with too few turns in the coil, which makes it difficult to adjust the acceleration to a low enough current value.

Where larger motors are used, considerable copper is required for the connections to these relays, and the heating of the relay is sometimes objectionable where the coil is in the circuit a considerable length of time. This difficulty can be overcome by using the same methods adopted for ammeters a good many years ago, viz., to provide the relays with shunt coils and connect them across a resistor. When ammeters are used it is necessary to provide a special shunt. The shunts have different current carrying capacity in order to make the meter indicate the proper current. The relays can use the starting resistance as their shunt, so that additional resistance does not need to be introduced into the circuit. The use of the starting resistance as a shunt for actuating the current limit relays has another advantage, namely, the shunt is automatically shortened each time an accelerating contactor closes. This reduces the voltage across the relay coils and permits the relays to be set for releasing at decreasing voltages and with a constant value of accelerating current, which provides for an automatic interlock to insure the operation of the relays in the proper sequence.

The relays can be held normally in the open position by mechanical connections to the accelerating contactors, which is the general practice when a series coil is used; or the relay coils may be energized in advance of the closing of the line contactor, thus permitting the relays to be mounted independent of the accelerating contactors. A number of schemes have been devised for obtaining these results and they have proved successful in practice.

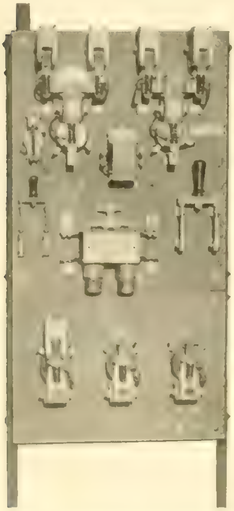

FIG. 1—REVERSING CONTROLLER WITH DYNAMIC BRAKE

Using the three-pole current limit relay illustrated in Fig. 2.

The heating of the relay coils may at first seem a disadvantage to the use of shunt coils. This same difficulty occurs with instruments and shunt wound motors; it can readily be taken care of by proper design. The coils are in the circuit only during the accelerating period, and their temperature is not materially increased unless the operation is very frequent. Well designed relays operate at a very low wattage and, therefore, the normal temperature rise of the coils, even if connected continuously to the circuit, will not introduce much error. If curve tests are made on the series-wound current-limit relays in common use today, it will be found that they are not very accurate. This has never proved a disadvantage, as they must always be set to give a starting current in excess of the maximum torque required, in order to insure starting the motor under unfavorable conditions. Both the relay and the contactor have a small time element so that, when the motor accelerates on light loads, the speed of the motor changes considerably while the relays and contactors are functioning and, therefore, the current peaks are materially reduced.

A new form of current limit relay has recently been produced which embodies a number of novel features. This relay is illustrated in Fig. 2. It consists of a double set of armatures. On one side of the coil are the accelerating armatures provided with contacts as shown in Fig. 3 as armatures *D*, *E*, and *F*. On the opposite side of the relay is the release armature *C*. The accelerating contacts are normally open, being held in this position by spring *H*. When the coil is magnetized the armature *C* closes, releasing the accelerating armatures *D*, *E* and *F*. These armatures, however, are held by the magnet against the spring *K*. By properly adjusting the air-gaps, these armatures release at different values of magnetism. Each armature closes a contact which energizes the coil on one of the accelerating contactors.

A typical scheme of connections for this relay is shown in Fig. 4. The relay is provided with two coils marked *A* and *B*. Coil *A* is connected across the starting resistor, coil *B* across the line. When the motor is first connected to the line, the armature is stationary and the full voltage drop is taken up by the resistor. Coil *A*, therefore, has full line voltage across its terminals. As the motor accelerates, the counter e.m.f. of the motor reduces the voltage drop across the resistor and, therefore, the voltage on coil *A* decreases, releasing armature *F*. This closes contactor *2* which short-circuits a section of the starting resistor. The current immediately increases so that the total drop remains the same. The increased current causes the motor to accelerate to a higher speed, which in turn reduces the voltage drop across the remaining portion of the resistor, at the same time reducing the magnetism in the relay to a value which permits armature *E* to release. This closes contactor *3* which short-circuits an additional portion of the starting resistor. A further increase in the speed of the motor permits armature *D* to drop. This closes contactor *4* and short-circuits the starting resistor. The voltage across coil *A* is now zero, but coil *B* is still energized and furnishes sufficient magnetism to retain armature *C* in the closed position.

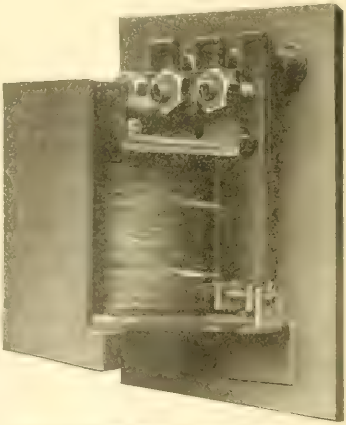

FIG. 2—THREE-POLE, CURRENT LIMIT RELAY

Operated by a shunt coil across the starting resistor.

Fig. 4 shows a push button starter of a type that has been described a number of times in previous Journal articles. The closing of the start button energizes coil *10* and closes contactor *1*. This bridges out the start button contacts and permits the motor to accelerate as described above. If the stop button is pushed, the control wiring is disconnected momentarily, which opens contactor *1* and also coil *B* of the accelerating relay. This drops armature *C* and resets armatures *D*, *E* and *F* so that they are again ready for accelerating the motor.

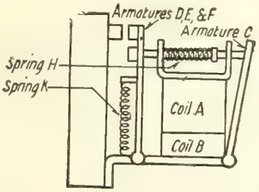

FIG. 3—DIAGRAMMATIC DRAWING OF THE THREE-POLE RELAY SHOWN IN FIG. 2.

The relay is designed so that the armature *C* closes at a relatively small value of magnetism; if the motor is restarted before it comes to rest, armature *C* will close, permitting armatures *F* and possibly armature *E* to release, depending upon the speed of the motor, in the same way that a current limit relay control of the series type will immediately drop the accelerating relays on one or more contactors, if the current is below their holding value.

Relays may be actuated by gravity, by springs or by a combination of both. A superficial consideration of the problem would indicate that the most desirable method of actuation is gravity. A careful consideration of the many applications indicate that a gravity actuated relay is sensitive to vibrations and must of necessity have considerable mass in the moving members. This makes a relay that is rather sluggish in operation for fast work, and one which is affected by its position of mounting and is sensitive to vibration. By designing the relay with very light moving parts, and using springs, a very reliable device can be produced, which is not seriously affected by the position of mounting or vibration and is very quick to respond to changed conditions. The relay shown in Fig. 2 is much faster than the contactors, Fig. 1, with which it is used, even when the contactors are made of pressed steel and have springs to give them quick motion. All of the relay armatures are of the clapper type. This design is usually better for dusty places, as dirt may accumulate around the plunger of the other type and interfere with the plunger where it passes through the frame.

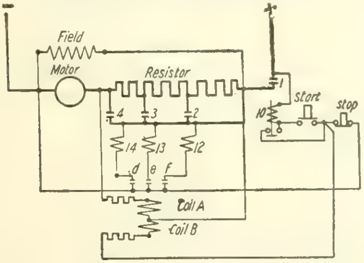

FIG. 4—DIAGRAM OF A PUSH BUTTON STARTER

Using the relay illustrated in Figs. 2 and 3.

A further analysis of the action of this shunt relay is given in Fig. 6. The upper curve shows the current taken by a motor during acceleration. The lower curve shows the voltage across the relay coils and, therefore, indicates the magnetism in the relay core, the ordinates representing voltage or magnetism and the abscissae time. The time spacings in the two curves coincide. On the lower curve vertical lines are drawn numbered *1*, *2* and *3*. The heavy lines represent the voltage or magnetism at which the accelerating armatures release, the dotted lines show the voltage or magnetism at which they retrieve or pick up. If a drum master switch is used to obtain speed control, Fig. 5, the contactors short-circuiting the resistance may be connected or disconnected at the will of the operator. If the motor has been accelerated to full speed, and it is desirable to decrease this speed, the master switch is moved back several notches, releasing several of the accelerating contactors. This increases the voltage across coil *A* of the relay and causes it to retrieve or pick up the accelerating armatures so that if the motor is again accelerated the automatic short-circuiting of the resistance takes place.

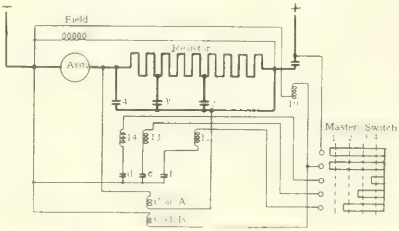

FIG. 5—DIAGRAM OF A CONTROLLER WITH DRUM MASTER SWITCH AND RELAY ILLUSTRATED IN FIGS. 2 AND 3

This diagram shows a method of controlling the amount of resistance in the armature circuit of the motor by moving the master switch from one notch to another.

The windings for coils *A* and *B* are fixed by the line voltage and are independent of the size of motor in the same way that the windings of an ammeter are fixed by the voltage across the shunt, and calibration is changed by changing the shunt. The accelerating resistance for any particular motor must be selected to give the proper current control. If the load on the motor is changed, the resistor is also changed. The voltage across the total resistor is fixed by the line voltage and if the resistor steps are not properly proportioned, no relay will give smooth acceleration. The use of a shunt accelerating relay has, therefore, the advantage that it can be adjusted once and need not be altered for any motor to which it is connected or the load on that motor. Since the relay responds to voltage only, it can be readily calibrated with a voltmeter. This is very much easier to do than to obtain the heavy current necessary to calibrate relays with series coils. The use of a small rheostat and voltmeter will enable an operator to check the calibration on any relay. The absence of mechanical connections between the relay and accelerating contactors makes it very easy to apply this relay to existing control equipment.

Many existing applications use lockout contactors. If these contactors are provided with shunt coils and the lockout feature is eliminated by substituting brass plugs or adjustable pieces for the iron ones, they can be made to operate satisfactorily with a shunt accelerating relay and true current limit acceleration obtained.

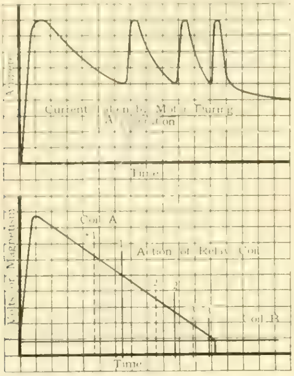

FIG. 6—CURVE SHOWING THE VOLTAGE TIME CURRENT RELATION WHEN THE RELAY SHOWN IN FIG. 2 IS USED

The upper curve shows the relation between time and the armature current of the motor. The lower curve shows the relation between time and the voltage across the relay coil. Since the magnetism in the relay is proportional to the voltage, this curve also shows the relation between time and the magnetism in the relav circuit. The two curves show the same time intervals so that the action of the relay is illustrated by the current curve. Both these curves are only approximate in shape and have been simplified for the purpose of illustration.

A relay of this type can be used to control deceleration by connecting the coil across the armature of the motor, Fig. 7. This permits the armatures *D*, *E*, and *F* to drop out at decreased values of counter e.m.f., and actuate contactors, which short-circuit sections of the dynamic brake resistor. The connections to the relay coil can be closed by opening the line contactor.

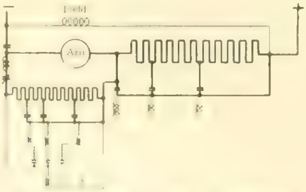

FIG. 7—DIAGRAM SHOWING THE USE OF A CURRENT LIMIT RELAY FOR [illegible] AUTOMATIC DECELERATION

This is the same relay illustrated in Fig. 2 with one coil omitted.

By using a shunt coil on the accelerating relay, heavy wire connections are avoided and it is as easy to connect or disconnect the relay coil as it is at present to connect or disconnect the actuating coil of a shunt-wound contactor. Actuating this relay by the drop across the accelerating resistor provides a device which is independent of the size of the motor or the load on the motor and does not require recalibration for changes in load conditions. Only one relay is required for all applications and only one coil for a given line voltage. In this way the spare parts are materially reduced and the maintenance simplified. Any relay can be used on any controller. By using the multiple type of shunt relay, as illustrated in Fig. 2, the number of coils is reduced and a single piece of apparatus can be used to accelerate all sizes of motors. The relay as shown in Fig. 2 is arranged for three accelerating contactors; other relays provide four accelerating contactors. If less than three contactors are used one of the armatures is not required and may operate signal light or other devices. The use of a coil in shunt to the starting resistor for controlling acceleration is old, but has not previously been worked out in much detail and its use has been very limited.

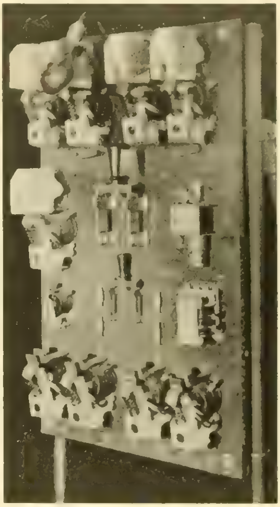

FIG. 8—REVERSING CONTROLLER

Using a four pole current limit relay similar to the one illustrated in Fig. 2. This controller is arranged for operation with a drum master switch for obtaining speed control.

This same principle can be applied to the lockout contactor and the coil connected across the line after the motor reaches full speed by means of a transfer interlock in order to retain it in the closed position. This involves the use of an interlock and it is an advantage to have the accelerating contactors of exactly the same design as the line contactors, both from a manufacturing and a maintenance standpoint. The interlock connections for current limit acceleration have been reduced from four per contactor with the old method of the single relay and transformer interlocks to one per contactor with the relay illustrated in Fig. 2. This halves the number of contacts now in general use, which consists of two contacts and a bridging member. If lockout contactors are used, an interlock and retaining coil are required to prevent the contactor from opening on light loads.

The Technical Story of the Synchronous Converter

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This is a semi-historical treatment of the [illegible] development of the synchronous converter as the author saw it. The various steps in the development are described, covering many of the earlier troubles, and methods tried for overcoming them. The early evidences of hunting which eventually led up to the use of copper dampers; e. m. f. regulation; 60 cycle converters; the three-wire converter; the inverted converter; the application of commutating poles; the coming of the synchronous booster and the split pole types of converters,—all are discussed. Representing principally the author's personal contact with the development, the story naturally is not to be considered as covering all types of apparatus.

THE WRITER feels competent to discuss this subject freely because he was one of the earliest in this field, and personally went through many of the principal troubles which developed in this line of endeavor. In fact, he believes that he was "over his head" in troubles with converters a considerable while before anyone else even knew that any serious difficulties existed. There is some question as to who actually suggested the earliest synchronous converter. The writer believed, in 1890—91, that he had devised a new and novel apparatus when he worked up the design specifications for an operative machine, but the records of the Patent Office said he was anticipated by Charles Bradley by some two or three years. However, it is not known whether Bradley ever built what might be called a commercial machine.

In 1891 there were only two main frequencies in use; namely, 133 and 60 cycles; also there were no polyphase circuits commercially available.

In 1891, the writer with several of his associates in the testing room made a self-starting polyphase converter while experimenting with a view to making a polyphase railway motor. It was desired to find what kind of starting conditions could be obtained on a railway motor supplied with alternating, instead of direct-current. An experimental direct-current multi-polar motor with slotted armature was equipped with collector rings, in addition to its commutator, and was supplied with suitable polyphase current of low frequency. This machine was brought up to speed as an induction motor and, at synchronism, delivered direct-current from its commutator for self-excitation, and to a lamp board. It was obvious that this machine could run synchronously and transform from alternating to direct current. This, therefore, constituted the first synchronous converter tested by the company with which the writer has been associated.

It was not until 1892, however, that deliberate efforts were made to transform from alternating to direct-current on a commercial scale. It was becoming recognized that the polyphase system offered great possibilities, and the synchronous converter began to be looked upon as one of the [illegible] In consequence, arrangements were made to obtain tests on a relatively large scale to determine the possibilities of such a device. For this purpose, a standard 150 hp, 500 volt, 850 r.p.m., four-pole railway generator was equipped with four collector rings. Suitable brushholders were arranged for operating on these collector rings, in addition to the usual brush holder equipment. This machine was started by means of a small direct-current machine belted to it. It was synchronized with a low-frequency supply alternator by means of lamps.

From the first, this machine operated in a very satisfactory manner as a synchronous converter and a long series of tests were carried on by the writer, assisted Mr. N. W. Storer, at that time one of his associates in the testing room. It was determined that this machine would commutate in just as satisfactory a manner as when acting as a direct-current generator.

Meanwhile the whole synchronous converter situation was being worked over and it was decided that 3600 alternations (30 cycles) was about the best frequency for such machines. This was higher than the frequency at which the tests were made, but it was felt that this increase was permissible, in view of the results already obtained at 3400 alternations (850 rev. per min., four poles).

About this time a Commission, which had taken up the development of the Niagara Falls power, had begun negotiations with the Westinghouse Company, with a view to getting certain electrical machinery constructed according to the designs of the Commission. The principal apparatus involved was a generator of 5000 hp capacity at 250 r.p.m. The design contemplated was of the "umbrella type" with external rotating field and vertical shaft. This construction as a whole was considered practicable by the Westinghouse engineers, but the electrical proportions of these generators were not acceptable. The Commission had decided upon a frequency of 2000 alternations, eight poles and 250 r.p.m., (16 2/3 cycles). One of the objects in this low frequency was to be able to operate commutator-type motors by means of alternating-current, as certain members of the Commission belived that this was the solution of the small alternating-current motor problem.

Based on a paper read at St. Louis before the American Institute of Electrical Engineers, Jan. 28, 1920.

The Westinghouse Company objected to this low frequency and proposed 16 poles at 250 revolutions, giving 4000 alternations per minute, (33 1/3 cycles), this being the nearest that could be obtained to its proposed standard of 30 cycles. One of the advantages claimed for the higher frequency was that it would be more suitable for synchronous converters, as the possible combinations of poles and speed would be very much greater than for 16 2/3 cycles. In fact, the lower frequency was considered to be more or less prohibitive as regards small or moderate capacity synchronous converters and induction motors, as their speeds would be too low. A compromise was finally made by selecting a 12 pole machine for the Niagara generator, thus giving 25 cycles and this was the origin of 25 cycles as a standard.

The members of the Commission were informed that we had been carrying on tests with a direct-current machine, modified into a converter and they witnessed the machine under load. The question came up as to whether such a machine had greater or less armature copper losses than a corresponding direct-current machine. Prof. Rowland, of the Commission, stated that he believed it to be the sum of the losses due to the alternating and direct-currents in the windings, upon which Prof. Geo. Forbes, of the Commission, claimed that it represented the difference. While such authorities were discussing the matter, the writer decided to make an actual test; so the following night he had the machine run as a converter to determine the comparative ratings, as a converter and as direct-current generator. It happened that this machine had a definite load limit as a direct-current generator, for it had been proved that with a certain current for four hours, it would begin to smoke. Consequently, tests were run to find the corresponding "smoking current" as a converter. The tests showed that, with 400 amperes load, about the same heating and smoking conditions were produced in the armature as with 280 amperes as a direct-current generator. This was a definite result, for it was known that this machine could not carry 400 amperes for any length of time as a direct-current generator. Therefore, the armature loss was less as a converter than as a direct-current generator. When this result was placed before the Commission, one of the members rejected the results and the other accepted them. However, the writer was convinced, and so were his immediate associates. This, he believes, was the first actual test which indicated the relative capacities of the machine as a converter and as a direct-current generator.

To verify by calculation, both the writer and Mr. R. D. Mershon undertook to analyze the losses in the armature copper when acting as a converter. Mr. Mershon attempted a mathematical solution whereas the writer undertook a simpler, but quicker method by plotting the calculated losses for each five electrical degrees of rotation of the armature. Curves were plotted and the losses during a complete cycle summed up. This was worked out over-night so that the results were available the next day. These showed 38 percent loss as a two-phase machine and 57 percent loss as a three-phase machine. This result checked closely with the actual test, considering that there were other losses involved. Mr. Mershon succeeded in his mathematical analysis after about a week's effort and, when he compared his results with those of the writer, they coincided almost exactly. Thus the writer believes that he was the first to work out the problem of the relative losses, while Mr. Mershon was the first to make a complete mathematical analysis.

In addition, some interesting experiments were carried on with this first converter. Among other tests, the writer brought this machine up to speed as a single-phase motor. By using the direct-current series winding as an alternating-current field winding, connected in series with the armature to form an alternating-current series motor, he started the machine from rest, brought it up to speed and then to synchronism. This forms, therefore, an early test of a large, series-wound, single-phase, commutator motor.

These early tests made the problem look so simple that apparently there was going to be no difficulty in developing commercial converters, provided suitable polyphase circuits were available. However, the real difficulties in converter operation did not develop until later. Based upon these successful results, the Westinghouse Company prepared a relatively large synchronous converter exhibit for the Chicago World's Fair in 1893. This exhibit comprised a 250 hp, two-phase, 60-cycle induction motor belted to a 500 hp, two-phase, 30-cycle a-c—d-c. generator. From the direct-current side of this generator 500 volt service was furnished for operating any 500 volt direct-current apparatus in the exhibit, while from the alternating-current side, 30-cycle, two-phase current was supplied to two synchronous converters, one of 500 and the other of 60 horse-power. No polyphase induction motor of such large horse-power had been shown before and the a-c—d-c. generator and the synchronous converters were both novel.

In looking over the original design specifications for the a-c—d-c. generator and the synchronous converter, dated Dec. 12, 1892, the writer finds some interesting matter, from a historical standpoint. The specification for the 500 hp converter calls for a six-pole, 30-cycle, 600 r.p.m., 525 volt machine much along modern lines of design. The pole pieces were laminated, but cast into the yoke, instead of bolted in. The armature was of the slotted type and with a "parallel type" winding, as in modern practice. This specification calls for a brush lifting device for the direct-current brushes, although as built, the machine did not use such a device. However, it indicates that the possibility of brush trouble with alternating-current starting was recognized. This converter was arranged to be started from low-voltage taps on an autotransformer, and it was intended that the machine should come up to synchronous speed on the lowest tap and then be transferred to full voltage by successive steps. This was carried out and the converter was started and synchronized in this manner. The specification also called for series field coils for compounding, but these were not incorporated in the actual machine. This converter was provided with a relatively small air-gap and light shunt field coils, compared with direct-current machines of corresponding dimensions. Thus this converter, *as specified,* was more nearly of the modern type than the designs which followed it during the next four or five years. Another interesting feature was that the field coils in starting were switched from series to three parallels and closed through a starting resistance, thus anticipating later practice.

The small converter, of 60 hp had cast-iron poles and yoke and operated at 900 r.p.m. This was also arranged to be started by autotransformers and with high resistance in the field.

The a-c—d-c. generator was similar to the above described synchronous converter, except that it had a large air-gap with relatively heavy field coils and was separately excited from a 120 volt exciter, of which the field excitation was varied to control the main generator voltage.

This exhibit was delayed and was not ready for operation until the first of July, 1893. On account of this delay, a number of other exhibitors thought that this exhibit, from the operating standpoint, was all a "bluff." However, the writer visited the exhibit about the first of July. He then reviewed the entire layout and assisted in testing some of the individual parts. Then one Sunday afternoon when there were no visitors around, but only exhibitors and attendants fixing up their exhibits, the 250 hp induction motor was started, bringing the a-c—d-c. generator up to speed. The large synchronous converter was then brought up to speed, also the small converter and various special apparatus, which were to be operated by current from these two converters, were set in motion, so that the entire stationary exhibit became very much alive in a few minutes.

When this exhibit was first operated, several unusual things occurred. One was a peculiar "beating" sound which occurred at times in the 60 hp, 500 volt converter. Under certain conditions of voltage and field strength, it made this peculiar noise and sparked to a certain extent, even when carrying no load. However, under normal operating conditions, there was no apparent trouble and no further investigations were made. This was probably the first observed case of "hunting" in a synchronous converter, but it was not serious enough to lead anyone to suspect an inherent difficulty. Another thing that developed was the relatively large input required to start the synchronous converter and bring it up to synchronism. Apparently this had considerable to do with the later practice of using starting motors to bring the converters up to speed. Starting the 500 hp converter from rest and bringing it up to synchronism proved to be about all that the 500 hp, a-c—d-c. generator could handle.

25-CYCLE CONVERTERS

As far as the writer's knowledge goes, the next step in the synchronous converter development was in connection with some 200 kw, 25-cycle converters to be used as exciters for the Niagara Falls Power Company's generating plant. These machines, built in 1894, were much along the lines of the World's Fair 500 hp converter, having laminated poles with no dampers, the need for the latter not having developed. One of these machines was operated from one of the Niagara generators in the Westinghouse shops and apparently ran all right except on one occasion, when there was a violent "pumping" or "beating" sound in the converter and it sparked very badly, so much so that it was cut off the circuit. When put on again, it ran satisfactorily and it was assumed that some mistake had been made which caused the preceding trouble. It was only after the converters were installed at Niagara Falls that the seriousness of the difficulty developed. It was found that these machines would not work as synchronous converters, due to apparent irregular rotation accompanied by violent sparking.

The Westinghouse company was also building 25-cycle converters under contract with a number of customers, apparently unaware that they were facing a very difficult situation. Outside of the two converters built for exciters, as mentioned above, the first serious trouble encountered was in connection with a couple of chemical plants at Niagara Falls. Several converters had been contracted for by two such plants and also the World's Fair 500 hp converter, already described, had been reconstructed into a 500 kw, 550 volt machine, which was set up in the main power house at Niagara Falls. This latter machine appeared to operate in a quite satisfactory manner, and we thus gained undue confidence.

The converters in the chemical plants at Niagara Falls were built along well known lines, having slotted armature, laminated poles, etc. These machines were troubled almost at once with hunting, as we now call it. In both plants, the converters refused to operate without bad hunting at times. It was then appreciated that the trouble indications in the shop tests, and in the Chicago exhibit, really meant something. The writer and Mr. C. F. Scott spent a long period working on these converters to stop the hunting, and all kinds of "stunts" were tried, one of which was short-circuiting part of the field coils. It had been noted that the exciting current varied as the machine hunted and therefore it was assumed that a heavy short-circuited path around the field poles might exert a steadying effect. This idea proved to be correct, but this damping was not sufficient to stop the hunting. However, in the course of these tests, the entire field circuit was disconnected from the commutator and closed on itself, on one of the machines, and it continued in synchronism and carried load as a converter through armature excitation alone and, what is more, there was absolutely no hunting under this condition. This was tried on the machines in both the chemical plants and was effective in both cases. An objection, however, was that the power-factor was quite bad, due to the large magnetizing current. Tests were made to determine what was going on during hunting and it developed that the armature of the converter was acting alternately as a generator and as a motor, and the armature magnetomotive force was reversing with each "beat." It appeared also, that the machine was alternately gaining and losing speed in respect to the supply system, during the beats.

While these tests showed clearly what was happening, the proper remedy did not suggest itself until afterwards. One thing was evident; namely, none of the converters would "hunt" when running without field excitation. Therefore, it appeared that, if the air-gaps were made small, as in induction motors, then the converters might operate without hunting and with magnetizing currents and power-factors comparable with induction motors. Plans were made to furnish new magnetic fields for one of the electro-chemical company's machines, in which an extremely small air-gap would be used. On trial this machine appeared to give quite satisfactory operation. Further tests indicated that the hunting problem was so serious that we might be obliged to go to this "induction converter" eventually for all synchronous converter work.

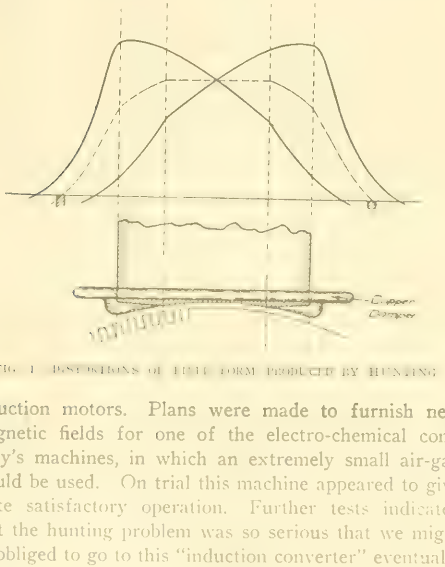


FIG. 1—DISTORTIONS OF FIELD FORM PRODUCED BY HUNTING

However, while this was being done, a further analysis was made of the general problem. The writer, with one of his associates, undertook to explore the magnetic field conditions in one of the Niagara converters during hunting to see what was actually occurring. A wooden arm was fixed over the commutator with a large number of uniformly spaced holes in it, through which metal contacts were pushed to the commutator surface. Voltmeter readings were taken for each position, over a wide arc of the commutator. It was found that the voltage readings were varying, with the beats in the machine, from a high value in one beat to a low value in the next. Plotting out these two extremes, two curves were obtained, as indicated in Fig. 1. Each of these represents the field flux distribution or "field form" under one of the extremes in the hunting action. Superposing these, it was obvious that the magnetic field was being alternately distorted in one direction and then the reverse. These curves explained many things. It was the study of these that led to the correct solution of the hunting problem. The writer attempted to do some figuring on the armature magnetomotive forces required to produce the distortions shown in Fig. 1, and while doing this, it occurred to him that as the larger part of the flux changes were at the edges of the poles, and as the poles had a very considerable "bevel," it might be possible to put a heavy copper plate under each pole edge, which would act as a secondary or "damper" to minimize the flux changes. At the same time, it was recognized that a closed circuit around the field pole itself had a steadying action. In consequence, the writer then proposed that a heavy copper damper, as shown in Fig. 1, be placed on the pole tips of a converter to see whether it would affect the hunting. In the latter part of 1896 a damper of this type was fitted on one of the Niagara exciters which, as said before, were utterly inoperative when installed in the Niagara plant. Immediately after this modification, this exciter operated with entire satisfaction as a converter and all hunting disappeared. Obviously, therefore, this was a revolutionary improvement. Immediately plans were made to install such dampers on other machines, and in each case hunting was overcome. This, therefore, was the origin in this country of the damper on synchronous converters.

The General Electric Co. at that time seemed to be getting along in a fairly satisfactory manner without any dampers, but the real reason for its better success was not fully appreciated. Its 25-cycle converters were built with solid steel poles, like its direct-current generators, and it was not recognized at first that these, in themselves, furnished enough damping capacity for most of the 25-cycle machines. A later attempt to use laminated poles disclosed the real reason for their previous success.

Meanwhile, however, various other devices to lessen hunting were being tried. Among these was the use of a heavy flywheel on the converter, both of flexibly and non-flexibly driven types. The non-flexibly driven flywheel apparently was not entirely effective. The flexibly driven flywheel was to a certain extent effective, according to statements at that time, although the writer had no personal experience with this construction.

Of course, after the hunting trouble on 25-cycle converters had been eliminated by the dampers, there was no necessity for following the "induction" type further, and that work was abandoned, except in one or two special instances. In 1894, the company had undertaken to build a 10 hp, 60 cycle converter. It was determined that it would operate without hunting, with its field coils short-circuited on themselves, thus forming an induction converter. A new field was then constructed with very short poles and without any field winding and with a very small air-gap, about the same as that of a small induction motor. This, at first, did not work as well as with the former field with the field coils short-circuiting themselves. It was then assumed that the short-circuited field coils must have had something to do with the operation and therefore on the new field, with small air-gap, a heavy copper one-turn field winding was placed, short-circuited on itself. With this winding, the operation was again quite satisfactory, and this machine was used for experimental purposes for many years.

Another type of "induction" converter was experimented with, about this time. In 1894 and 1895, the Westinghouse company, in putting up its new shops at East Pittsburgh, had adopted 25 cycles, two-phase for its power system. A number of 125 and 250 volt converters were designed and built for the testing rooms. These converters operated fairly well except that they hunted at times, the copper damper not yet being devised. This hunting led the writer to consider the use of one of these converters as a synchronous running machine without any field winding whatever. A set of circular punchings, of the same bore as the armature diameter, was slipped over the outside, making good magnetic contact with the outside of the armature core, and thus forming a completely closed magnetic circuit around the armature winding. This armature was then driven at synchronous speed by means of another machine, two-phase alternating-current was supplied to the collector rings, and direct-current was delivered at the commutator. This was practically the equivalent of the so-called "permutator" brought out in Europe some years later. This machine was quite sensitive to brush setting and the direct-current voltage regulation was relatively poor.

The foregoing covers pretty well the development of the 25 cycle converter. By 1896, it was becoming fairly well established and by 1898, with improved dampers, began to be recognized as a thoroughly commercial machine. Most of the converters were operated from engine-type alternators and it was recognized that the generating conditions had something to do with converter troubles.

Another condition which came up was high ohmic line drop. Cases were encountered where severe hunting developed, even in converters with fairly good dampers. Investigations showed that increase in line voltage helped materially and it began to be recognized that large transmission drop was harmful for converters. The writer made extended tests at one time to determine the effect of resistance and reactance on the hunting of synchronous converters. The synchronous machine for this test was provided with high damping power. The results indicated that high ohmic drop between the generator and the synchronous load was harmful, depending upon the amount of drop. With 25 percent ohmic drop, there was almost sure to be hunting, even with a well damped machine. With 20 percent ohmic drop, the hunting was the rule, while with 15 percent drop, hunting might occur, under some conditions, but it was the exception, rather than the rule. With materially less than 15 percent ohmic drop in the circuits, apparently no hunting was produced. Similar tests with reactance instead of resistance, showed that, up to as high as 60 percent reactance, there was no material effect, as far as hunting was concerned. In consequence, the conclusion was reached that resistance, rather than reactance, was the harmful element in a large line drop.

The interesting fact about these results is that all later experience which the writer has encountered agrees closely with these early tests.

After the development of the damper, it was discovered that the amount of damping on each machine had not only an appreciable effect in eliminating its own hunting, but also a damping effect on the system as a whole, and thus lessened the trouble on other converters. In one case, where 60 cycle converters without dampers had been installed, in connection with a waterwheel plant, there was, occasionally, slight hunting, principally under heavy load. The customer requested that an attempt be made to overcome this trouble. As additional converters were being installed, he was told that the trouble would be lessened when the new converters were put into operation. He was very doubtful about this, but upon the installation of the new machines, he reported that the hunting of the earlier machines was overcome. This was accomplished by putting quite ample dampers on the newer machines, thus introducing a steadying element into the system. In another case, in a large interurban railway system, it was found that the converter substations farthest from the main generating plant, were subject to hunting on heavy load. In this case, a new substation on the same line, but still farther away, was equipped with converters which had large damping capacity, and this quieted the substation which formerly had shown signs of trouble.

In 1898 and 1899, the 25-cycle converter was coming to the front very rapidly. In the latter year the Manhattan elevated railway in New York decided to electrify, and the first order for synchronous converters comprised 26 units, each of 1500 kw. Sometime later a similar order for the New York Subway consisted of thirty-four 1500 kw units. Within a comparatively short time, the total number of converters of this capacity for these two companies aggregated nearly 100. This was far above anything ever undertaken in the direct-current generator line, and thus it may be seen that, even at this early date, about twenty years ago, the 25-cycle converter had already outgrown its direct-current competitor.

60-CYCLE CONVERTERS

The success of the 25 cycle converter led to corresponding attempts to build 60 cycle machines. Much greater difficulties were encountered than in the 25 cycle machine, due to inherent limitations dependent upon the frequency. The first 60 cycle converter built by the Westinghouse company was undertaken in the latter part of 1896. This was a 250 kw, 14 pole, 514 r.p.m. machine designed for a range of 230 to 340 volts, this range to be taken care of by variations in the alternating-current supply voltage by means of a regulator. This machine was built without dampers, but, if the writer remembers rightly, it was operated from a generating system driven by a water wheel.

Shortly after this, a number of 60 cycle converters were put out. It was soon found that 600 volt, 60 cycle machines were quite sensitive to flashing and ultimately it developed that this was due to inherent limitations in the machines themselves, as constructed in those days. The limiting peripheral speed of the armature cores and commutators was such that apparently good electrical and magnetic proportions were not obtainable. With the maximum allowable peripheral speed of the cores of those times, about 7000 to 7500 feet per minute, the pole pitch of the machines was only about 12 inches and this did not allow space enough for both a good pole width and an ample interpolar space. If the interpolar space was made wide enough to give the desired commutating conditions, then the pole itself became too narrow to give the necessary pole width to prevent unduly high "peak voltages" between commutator bars. Six hundred volt direct-current machines with less than 12 inches pole pitch had been good practice, but not with the limitations imposed by the 60 cycle frequency. In the direct-current generator, frequency and commutator peripheral speed do not appear as limitations to the same extent as in a synchronous converter, where the pole pitch and the distance between the adjacent neutral points on the commutator are fixed entirely by those two conditions. In the 60 cycle, 600 volt converter, with a commutator peripheral speed of 4500 ft. per minute, the distance between adjacent neutral points is 7.5 inches, regardless of the number of poles or revolutions. Within this short distance of 7.5 inches, it was then possible to use thirty-six commutator bars, for 600 volts. With this number of bars, the average volts per bar would be 16 2/3, which was believed to be permissible. However, with the relatively narrow pole face, compared with the pole pitch, as used in the early 60 cycle converters, the peak value of the voltage per bar was nearly double the average, and attained a dangerous value in regard to flashing, in machines of relatively large capacity. However, if the poles were made considerably wider, while retaining the same pole pitch, the danger of flashing due to high voltage between bars was lessened, but the commutating zones became so sharply defined that it took an expert to operate the machines without danger of sparking. Obviously, whichever way we moved we encountered either a serious sparking or a flashing condition. Adding to the above difficulties the fact that 60 cycle engine-type generators were inferior to 25 cycle units, in constancy of frequency, ability to operate in parallel, etc., it may be seen that the 60 cycle problem was not any too promising for 600 volt work, even with dampers to prevent hunting. Moreover, when the damper was developed for 25 cycle converters, it was found that equally good results were not obtainable in 60 cycle converters, for it was not possible, with any of the designs brought out at the time, to apply anything like as large damping capacity, as was possible with 25 cycles. The 60 cycle poles were much smaller, thus allowing less space under the poles. Furthermore, with the higher frequency, the open armature slots produced quite heavy eddy current losses in the dampers themselves. Nevertheless, with all these disadvantages, dampers were applied to many of the early 60 cycle machines with material benefit, especially on units operated from waterwheels.

While the damper was being developed for 60 cycle converters, an interesting discovery was made by one of the engineers installing these machines on a western transmission system. Here, there was hunting at times due, apparently, to ohmic drop in the line. The generators were waterwheel driven. Hunting of the converters was more pronounced with heavy loads, indicating line drop as one cause of the trouble. In this station there was a 100 hp induction motor for driving certain apparatus. The installing engineer noticed that hunting never occurred when this induction motor was connected to the circuit. In consequence, when hunting did occur with the motor off the circuit, he deliberately threw it on the circuit to determine whether it really did have any effect, and it was found that this stopped the hunting. In another installation where there was hunting of 60 cycle engine-type generators, operated in parallel, and of converters operated from these generators, the writer prepared a special induction motor to operate in parallel with the converters. This was a motor of 50 hp normal rating, but which was operated under such increased voltage conditions that the magnetizing current was about equal to the rated full load current of the motor. When this machine was connected to the above system in parallel with the converters, it invariably stopped the hunting of the latter, even though there was hunting between the two generators which supplied the converters. For a time, this was looked upon as one solution of the hunting problem, but further perfection of the dampers on the converters themselves so far eliminated the trouble that the induction motor method of damping was abandoned.

A next step, which was of material benefit, was the advent of the turbogenerator. This eliminated the element of periodic frequency variations found with the engine-type generators. However, even with this improvement, the 60 cycle converter was still more or less sensitive to sparking and flashing.

(To be continued)

Switchboard Meter Connections for Alternating Current Circuits-II

Two-Phase Circuits

J. C. Group

THE TWO-PHASE four-wire circuit consists of two single phase circuits, in one of which the voltage is 90 degrees out of phase with that in the other. Circuits, such as the one shown in Fig. 14, are usually connected so that the voltage in phase B is a maximum in the direction from line *2* to *4* 90 degrees after the voltage in phase A is a maximum in the direction *1* to *3*. This is indicated in the vector diagram, Fig. 15, where the vector $E_{2\,4}$ is shown 90 degrees behind $E_{1\,3}$. Since a current transformer is located in line *4*, it is more convenient to consider the positive direction of voltage in phase B from *4* to *2*, so that the current in line *4* may be considered positive when it is flowing in the direction of power transmission. The voltage $E_{4\,2}$ is 180 degrees from $E_{2\,4}$ and is therefore 90 degrees ahead of $E_{1\,3}$. The positive directions through the meters, as indicated by the small arrows, are in accordance with the assumption that the voltage $E_{4\,2}$ and current I_4 are 90 degrees ahead of $E_{1\,3}$ and I_1.

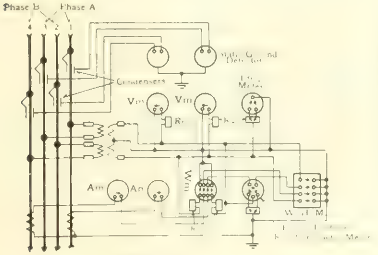


FIG. 14

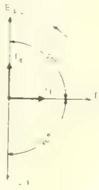


FIG. 15

FIG. 14—METERS ON A TWO-PHASE, FOUR-WIRE CIRCUIT

FIG. 15—VECTOR DIAGRAM FOR TWO-PHASE, FOUR-WIRE CIRCUITS

In the combination of meters shown in Fig. 14, there is an ammeter and a voltmeter for each phase. An element of the polyphase wattmeter and of the watthour meter is connected to each of the two phases the same as for single-phase circuits, so that these meters measure the sum of power used in the two phases, or the total power in the two-phase circuit. This measurement of power may also be explained in connection with the vector diagram in Fig. 15. The current and voltage coils in the right hand element of the wattmeter and the upper element of the watthour meter are connected to the current transformer and the voltage transformer in phase A, so that the current which flows through the current coils is represented by I_1 and the voltage impressed on the voltage coils is represented by $E_{1\,3}$, and as shown for unity (100 percent) power-factor, the power measured by these respective elements is expressed by $P_1 = E_{1\,3}\,I_1$, since the angle of lag or lead is zero, and its cosine is unity. Similarly the power measured by the left hand element of the wattmeter and the lower element of the watthour meter is represented by $P_2 = E_{4\,2}\,I_4$. Therefore, the total power P is equal to $E_{1\,3}\,I_1 + E_{4\,2}\,I_4$, or for a balanced condition, where $E_{1\,3}$ and $E_{4\,2}$ are equal and I_1 and I_4 are equal, the equation reduces to the simple form for the power in a two-phase circuit, that is $P = 2EI$ where E is the phase voltage and I the line current. If the power-factor is not unity, the equation must be written $P = 2EI \cos \phi$ where ϕ is the angle of lag or lead, and the cosine of the angle ϕ is the power-factor.

One frequency meter connected to either phase is sufficient, since the frequency is the same in both phases. A single-phase power-factor or reactive factor meter is shown connected to one phase which, for balanced two-phase loads, is correct for the circuit, as the power-factor would be the same in both phases. In cases where single-phase loads with various power-factors are taken from a two-phase system, and it is desired to have an indication of both phases, it is necessary to use a power-factor or a reactive factor meter on each phase. For indicating grounds on any of the four lines, two single-phase, static ground detectors are used, one being connected to each phase.

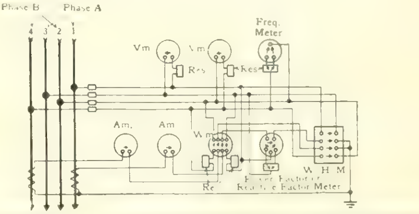


FIG. 16—METERS ON A TWO-PHASE-FOUR-WIRE CIRCUIT WITHOUT VOLTAGE TRANSFORMERS

A combination of meters is shown in Fig. 16 similar to that in Fig. 14, except for voltages low enough so that voltage transformers are not necessary. The voltage coils of the meters are connected directly to the lines through fuses, and these voltage circuits are not grounded. The static ground detectors are not used because they are not adaptable to low-voltage circuits. The current transformers are connected to the current coils of the meters in the same manner as in Fig. 14.

A combination of meters is shown in Fig. 17, in which there is but one ammeter and one voltmeter, which may be shifted from one phase to the other by means of an ammeter switch and a voltmeter switch. The developments of these switches, which are shown in Fig. 18, illustrate how the connections are made in the circuits for the different positions of the switches.

For the ammeter switch in the off position, point *4* is open and points *1*, *2* and *3* are connected together, so that the currents from the current transformers in lines *1* and *4* combine and flow back on the ground wire from point *2* without any current flow through the ammeter. For position *1*, points *1* and *4* are connected together, and points *2* and *3* are connected together, so that the current from the current transformer in line *1* flows out on the wire from point *4* and through the ammeter to point *2*, thus giving a reading of the current in phase *A*, and then combines with the current from the current transformer in line *4* and returns on the ground wire from point *2*. For position *2*, points *3* and *4* are connected together, and points *1* and *2* are connected together, so that the current from the current transformer in line *4* flows out on the wire from point *4*, and through the ammeter to point *2*, thus giving a reading of the current in phase *B*, and returns on the ground wire from point *2*. For the voltmeter switch in the off position, all the points are open and the voltmeter is entirely disconnected. For position *1*, points *2* and *3* are connected together and points *5* and *6* are connected together so that the wire from the voltage transformer, corresponding to line *1*, is connected to one terminal of the voltmeter, and the wire from the voltage transformer, corresponding to line *3*, is connected to the other terminal, so that the voltmeter gives a reading of the voltage of phase A. For position *2*, points *1* and *2* are connected together and points *4* and *5* are connected together, so that the wire from the voltage transformer, corresponding to line *4*, is connected to one terminal of the voltmeter and the wire from the voltage transformer, corresponding to line *2*, is connected to the other, so that the voltmeter gives a reading of the voltage of phase *B*.

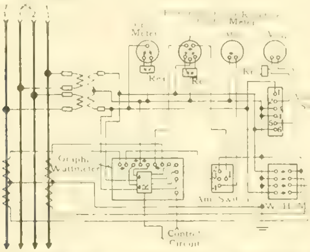


FIG. 17 METERS ON A TWO-PHASE, FOUR-WIRE CIRCUIT
Where voltmeter and ammeter switches are used.

The polyphase graphic wattmeter is connected so that it measures all the power in the two-phase circuit. In addition to making the graphic record, this meter is provided with a pointer and scale so that it serves also as an indicating meter.

The group of meters shown in Fig. 18 is the same as in Fig. 17, but the connections are for a circuit where voltage transformers are not used. The polyphase graphic wattmeter has the ends of the two voltage coil windings connected together inside of the meter case and one lead is brought out from that junction. Therefore, it is not possible to keep the two circuits for the voltage coils separate, and it is necessary to use two special resistors connected in the voltage circuits as shown, in order to adapt the meter to this kind of a circuit.

TWO-PHASE THREE-WIRE CIRCUITS

The two-phase three-wire system differs from the four-wire system in that one line is used as a common return for both of the phases, and therefore only three wires are necessary. The phases are not separate, one end of each phase winding being connected to the common return line. Fig. 19 shows a two-phase three-wire circuit in which line *2* is the common return or neutral for the two phases.

The relations of voltages and currents in the circuit can best be understood by referring to the vector diagram in Fig. 21, in which $E_{1\,2}$ represents the voltage in phase *A* when in the direction from line *1* to line *2*, and $E_{2\,3}$, 90 degrees behind $E_{1\,2}$, represents the voltage in phase *B* in the direction from line *2* to line *3*. I_1 and I_3 are used to represent the currents in phase with $E_{1\,2}$ and $E_{2\,3}$ respectively. It is most convenient to consider the component of the current in line *2* which belongs to phase *B* in terms of the current in line *3*, since the two currents are the same, except that one is in a negative direction with reference to the positive direction in the circuit, and it is for this reason that the current in phase with $E_{2\,3}$ is represented by $-I_3$. It is necessary to connect current transformers in lines *1* and *3* in order to make use of the currents that belong to the respective phases, and in considering phase *B* it is more convenient to use the voltage $E_{3\,2}$ in the direction from line *3* to line *2* and the current I_3 when in a positive direction, than to use $E_{2\,3}$ and $-I_3$. $E_{3\,2}$ and I_3 are 180 degrees from $E_{2\,3}$ and $-I_3$, and are shown in this position in the diagram. The current I_2 in line *2* in a positive direction is equal to the vector sum of $-I_1$ and $-I_3$ and, when $-I_1$ and $-I_3$ are equal as in the case of a balanced load, I_2 is equal to $\sqrt{2}$ times the phase current, since $-I_1$ and $-I_3$ are 90 degrees apart. In such a circuit it is necessary that the neutral line lead be made enough larger than the other leads to carry this proportionally greater current.

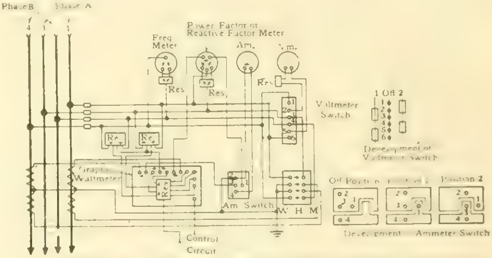


FIG. 18 METERS ON A TWO-PHASE, FOUR-WIRE CIRCUIT WITHOUT VOLTAGE TRANSFORMERS

There is also present a voltage between lines *3* and *1*, due to the phases being connected as was pointed out above. This voltage $E_{3\,1}$ when in the direction from line *3* to line *1* is equal to the vector sum of the voltages $E_{3\,2}$ and $E_{2\,1}$ $(-E_{1\,2})$ and, for balanced voltages 90 degrees apart, is equal to $\sqrt{2}$ times the phase voltage.

As shown in Fig. 19, connections to the meters on the secondary side of the current and voltage transformers are exactly the same as for the two-phase four-wire circuits. For the static ground detectors, one condenser for each detector is connected to the neutral wire.

In Fig. 20 is shown a similar set of meters connected to a two-phase, three-wire circuit where voltage transformers are not used. Extra resistors for the graphic recording wattmeter are not necessary as the returning currents from the voltage coils may reach the respective phases directly through the neutral wire. The developments of the voltmeter switch and the ammeter switch are as shown in Fig. 18.

FOUR-PHASE CIRCUITS

The four-phase circuit consists of an interconnected two-phase arrangement, where the middle points of the two-phase windings are connected together. A neutral lead may be taken out from this junction point, making a four-phase, five-wire circuit. Without the neutral the circuit is four-phase, four-wire.

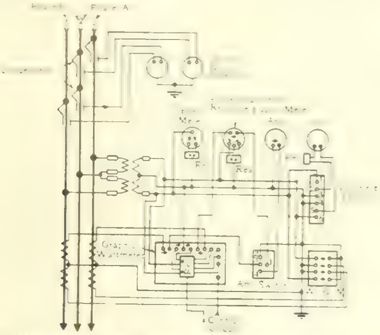


FIG. 19—METERS ON A TWO-PHASE, THREE-WIRE CIRCUIT

A four-phase five-wire circuit is shown in Fig. 23, The middle points of the two-phase windings are connected at the point *0* and line *5* is the neutral. In a system of this kind the load circuits are usually taken off between the main lines and the neutral, so that the current which flows out on any line may return on the neutral. When the load on the system is balanced, there will not be any current flowing in the neutral line, as the current which flows out on one line of each phase flows through the two load circuits connected in series between the two lines of each phase respectively, and returns on the other line. When the load is unbalanced, so that the current in one of the two load circuits connected in series between the two lines of each phase is greater than the current in the other, a current, equal in amount to the difference between the currents of the two load circuits, must flow in the neutral line. For this reason it is necessary to connect a current transformer in each of the four lines of the system in order to make complete measurements. The voltages impressed on the various load circuits is the voltage from the respective lines to neutral, or for a balanced condition is one-half of the two-phase voltage. The ammeter is arranged so that it can be connected to any one of the four current transformers by means of an ammeter switch. The development of the ammeter switch shows how the above connections are made for the different positions.

For the off position, points *1*, *4*, *7*, *10* and *13* are open, so that the ammeter is entirely disconnected, and points *2* and *3*, *5* and *6*, *8* and *9*, *11* and *12*, are respectively connected together, so that the current from the current transformer in line *1* flows to point *2* on the ammeter switch, and out from point *3* through the right-hand element of the polyphase wattmeter and returns on the ground wire. The current from the transformer in line *2* flows to point *5* on the ammeter switch and out from point *6* through the left-hand element of the wattmeter and returns on the ground wire. The current from the transformer in line *3* flows out on the ground wire through the right-hand element of the wattmeter to point *9* on the ammeter switch and returns on the wire from point *8*. The current from the transformer in line *4* flows out on the ground wire through the left-hand element of the wattmeter to point *12* on the ammeter switch and returns through the wire from point *11*. In tracing the circuits of the individual current transformers it must be understood that in some parts of the circuits, the individual currents do not remain separated, but are combined with the currents from some or all of the other current transformers. But a wire from one end of each current transformer is taken to a point on the ammeter switch and therefore the currents are separated in the ammeter switch, so that they may be singly connected through the ammeter.

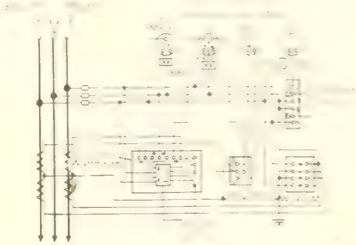


FIG. 20—METERS ON A TWO-PHASE THREE-WIRE CIRCUIT WITHOUT VOLTAGE TRANSFORMERS

For position *1*, points *5* to *13* remain the same as in the off position, but points *1* and *2* are connected together and points *3* and *4* are connected together, so that the current from the current transformer in line *1* flows to point *2* on the ammeter switch, and out from point *1* through the ammeter, (thus giving a reading of the current in line *1*) then to point *4* and out from point *3* through the right-hand element of the wattmeter and returns on the ground wire. For position *2*, points *1* to *3* and *8* to *13* are the same as in the *off* position, but points *4* and *5* are connected together and points *6* and *7* are connected together, so that the current from the current transformer in line *2* flows to point *5* on the ammeter switch and out from point *4* through the ammeter, (thus giving a reading of the current in line *2*) then to point *7* and out from point *6* through the left hand element of the wattmeter and returns on the ground wire. For position *3*, points *1* to *6* and *11* to *13* are the same as in the off position, but points *7* and *8* are connected together and points *9* and *10* are connected together, so that the current from the current transformer in line *3* flows out on the ground wire through the right-hand element of the wattmeter to point *9* on the ammeter switch, and out from point *10* through the ammeter, (thus giving a reading of the current in line *3*) then to point *7* and returns on the wire from point *8*. For position *4*, points *1* to *9* are the same as in the off position, but points *10* and *11* are connected together, and points *12* and *13* are connected together, so that the current from the current transformer in line *4* flows out on the ground wire through the left hand element of the wattmeter to point *12* on the ammeter switch and out from point *13* through the ammeter, (thus giving a reading of the current in line *4*) then to point *10* and returns on the wire from point *11*.

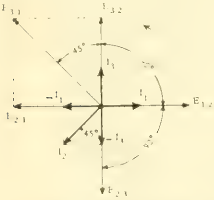


FIG. 21 VECTOR DIAGRAM FOR A TWO-PHASE, THREE-WIRE CIRCUIT

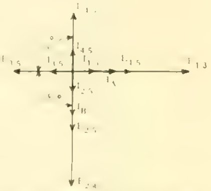


FIG. 22—VECTOR DIAGRAM FOR A FOUR-PHASE, FIVE-WIRE CIRCUIT

The polyphase wattmeter is connected to measure the total power in the four-phase circuit, and in order to do this, the secondary currents from two current transformers connected in the lines of each phase of the two-phase circuit are taken through each of the wattmeter current coils, and these coils must be of suitable capacity to take care of these combined currents. The vector diagram in Fig. 22 shows the relations of voltages and currents in the four-phase, five-wire circuit for balanced load and unity power-factor, and also provides a ready means for checking the way that the wattmeter measures the power. The voltage vectors $E_{1\,5}$, $E_{2\,5}$, $E_{3\,5}$ and $E_{4\,5}$, 90 degrees apart represent the voltages impressed on the respective load circuits between the four lines and neutral, and $I_{1\,5}$, $I_{2\,5}$, $I_{3\,5}$, and $I_{4\,5}$ represent the respective currents in phase with the voltages. The two-phase voltages are represented by $E_{1\,3}$ and $E_{2\,4}$.

The current transformers are connected so that the current which flows through the right-hand element of the wattmeter is equal to $I_{1\,5} - I_{3\,5}$ (vectorially), which is shown on the vector diagram as I_A. For the conditions assumed, this current is equal to twice the four-phase line current since the two currents combined are in phase. Similarly I_B, the vector difference of $I_{2\,5}$ and $I_{4\,5}$ is the current which flows through the left hand element of the wattmeter. The voltage transformers are connected across the two-phase voltages, and if the meter has an ordinary calibration for these voltages, the power, P_M, measured by the meter, is equal to $2 \times 4\,EI$, where E is the four-phase voltage (one-half the two-phase voltage) and I is the four-phase line current.

The actual power, P, for this circuit, when the angle of lag or lead is zero, is $4EI$ which is one-half the meter indication, and therefore the meter must be either specially calibrated or be used with a multiplier of one-half.

The wattmeter connection shown in Fig. 23, as explained, gives correct indications regardless of the unbalancing of currents so long as the voltages do not become unbalanced. When the voltages are unbalanced a small error may be introduced due to the four-phase voltages not being equal to one-half of the two-phase voltage.

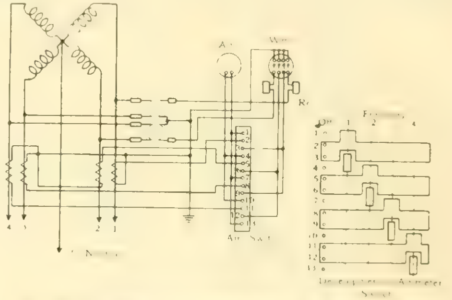


FIG. 23 AMMETER AND WATTMETER ON A FOUR PHASE, FIVE-WIRE CIRCUIT

In addition to connecting load circuits between each of the four lines and neutral in a four-phase five-wire circuit, it is possible to connect loads between any two of the main lines. A polyphase wattmeter (specially calibrated or used with a multiplier of one-half connected as shown in Fig. 23, will correctly measure the power in the entire circuit when loads are taken from the system in that way also, as will be evident from the explanation of the four-phase, four-wire circuit shown in Fig. 24. This circuit is the same as that shown in Fig. 23 except that the neutral is omitted and for simplicity the ammeter connections are not shown.

In analyzing a four-phase, four-wire circuit, such as shown in Fig. 24, it is necessary to construct a vector diagram, as shown in Fig. 25. This diagram is for the condition of unity power-factor and balanced load. The four generated voltages are represented by the vectors $E_{0\,1}$, $E_{0\,2}$, $E_{0\,3}$, and $E_{0\,4}$ which are 90 degrees apart. The voltage $E_{1\,2}$ between lines *1* and *2* in the direction from line *1* to line *2* is equal to $E_{0\,1} - E_{0\,2}$ (vectorially) and being 45 degrees ahead of $E_{0\,1}$ is equal to $\sqrt{2}$ times the generated four-phase voltage. Likewise $E_{2\,3}$, $E_{3\,4}$, and $E_{4\,1}$, being derived in a similar manner, represent the voltages between the other lines. For the four-phase circuit under consideration, the voltages $E_{1\,2}$, $E_{2\,3}$, $E_{3\,4}$ and $E_{4\,1}$ are the voltages impressed on the respective load circuits and may be thought of as the four-phase line voltages. $I_{1\,2}$, $I_{2\,3}$, $I_{3\,4}$ and $I_{4\,1}$ represent the currents in the respective load circuits in phase with the four-phase line voltages. The current I_1 in line *1* is equal to $I_{1\,2} - I_{4\,1}$ (vectorially) and, being 45 degrees behind $I_{1\,2}$ is equal to $\sqrt{2}$ times the phase or load currents. Similarly I_2, I_3 and I_4, represent the currents in the other three lines.

In Fig. 24, the current transformers are connected so that the current that flows through the right hand element of the wattmeter is equal to $I_1 - I_3$ (vectorially) which, as indicated by I_A on the vector diagram in Fig. 25, represents twice the line current. Likewise, I_B, equal to twice the line current, represents the current that flows through the left-hand element of the wattmeter. Since the voltage coils of the meter are connected to the two-phase voltages, the total power, P_M, measured by the wattmeter is equal to $4\,E_2\,I$ where E_2 represents the two-phase voltage and I the four-phase line current. $E_2 = \sqrt{2}\,E$ where E is the four-phase line voltage, and therefore the former equation becomes $P_M = 4\sqrt{2}\,EI$. Then dividing this result by *2*, which would have to be taken care of either by special calibration of the meter or by the use of a multiplier, gives the actual power $P = 2\sqrt{2}\,E\,I$ which is correct for the four-phase, four-wire circuit, when the angle of lag or lead is zero.

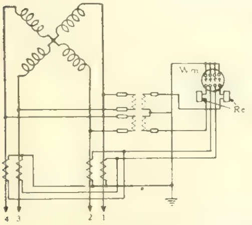


FIG. 24—WATTMETER ON A FOUR-PHASE, FOUR-WIRE CIRCUIT

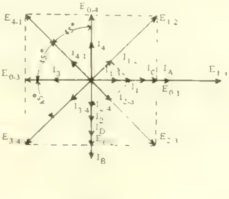
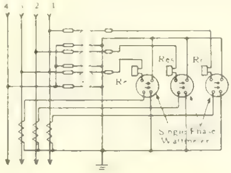


FIG. 25—VECTOR DIAGRAM FOR A FOUR-PHASE, FOUR-WIRE CIRCUIT

Load circuits may also be connected between lines *1* and *3* and lines *2* and *4* the same as for a two-phase four-wire circuit. The two-phase voltage impressed on these load circuits is equal to twice the generated four-phase voltage and $\sqrt{2}$ times the four-phase line voltage. $I_{1\,3}$ and $I_{2\,4}$ represent the currents in the load circuits connected between lines *1* and *3* and lines *2* and *4* respectively. For a balanced load of this kind, the current which flows through the right-hand element of the wattmeter is twice the line current, as indicated by I_C on the vector diagram. Likewise I_D represents the current that flows through the left-hand element of the meter. Therefore, the total power, P_M, measured by the wattmeter is *4 EI*, where E is the two-phase voltage and I the two-phase line current. This result divided by two gives actual power $P = 2\,EI$ which is correct for the two-phase circuit, when the angle of lag or lead is zero.

The power on a four-phase, four-wire circuit can be measured by three single-phase wattmeters connected as shown in Fig. 26. Since the current that flows out on any line must return on some other line, only three current transformers are required to insure measurement of all the currents that can flow. Three voltage transformers are necessary. The connections are made as though one line were used as a return for the other three, the current transformers being connected in the three lines, and the voltage transformers being connected between these respective lines and the fourth line. The voltage transformer connected between lines *2* and *4* would have to be for a higher voltage than the other two, due to its being connected across the two-phase voltage which is $\sqrt{2}$ times the four-phase line voltage. In the vector diagram for this circuit shown in Fig. 27, $E_{1\,2}$, $E_{2\,3}$, $E_{3\,4}$ and $E_{4\,1}$, represent the four-phase line voltages, and I_1, I_2, I_3 and I_4 the line currents for a balanced load and unity power-factor. $E_{2\,4}$ represents the two-phase voltage between lines *2* and *4* across which the one voltage transformer is connected. Then the power measured by the right-hand wattmeter is $0.5\sqrt{2}\,EI$ where E is the four-phase line voltage and I the line current. The factor $0.5\sqrt{2}$ is introduced because the current I_1 is 45 degrees out of phase with the voltage $E_{1\,4}$ and the component of this current in phase with the voltage is $0.5\sqrt{2}\;I_1$. The power measured by the middle wattmeter is $\sqrt{2}\,EI$, since the voltage for this meter is $\sqrt{2}$ times the four-phase line voltage and the current is in phase with the voltage. The power measured by the left-hand wattmeter is $0.5\sqrt{2}$ EI, the same as for the right-hand meter. Therefore the total power, as given by the sum of the three meter indications, is equal to $2\sqrt{2}\,EI$ which is correct for the circuit. This method of measuring power is independent of unbalancing of currents and voltages.



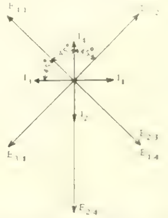
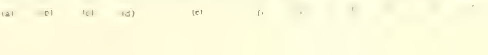


FIG 26—THREE SINGLE-PHASE WATTMETERS ON A FOUR-PHASE, FOUR-WIRE CIRCUIT

FIG 27—VECTOR DIAGRAM FOR THE FOUR-PHASE, FOUR-WIRE CIRCUIT SHOWN IN FIG. 26

CORRECTION

In the Journal for January, p. 25, left column, the last two lines above Fig. 1 should have been under the heading "Selection of Positive Directions." On some copies the last three symbols disappeared from Fig. 3. The complete illustration appears below.



Electrical Characteristics of Transmission Circuits-VII

Performance of Short Transmission Lines

(Effect of Capacitance Not Taken Into Account)

WM. NESBIT.

THE PROBLEMS which come under the general heading of short transmission lines are those in which the capacitance of the circuit is so small that its effect upon the performance of the circuit may, for all practical purposes, be ignored. The effect of capacitance is to produce a current in leading quadrature with the voltage, usually designated as charging current. This leading component of current in the conductor does not appear in the load current at the receiving end of the circuit. It is zero at the receiving end of the circuit but increases at nearly a uniform rate as the sending end of the circuit is approached, at which point it ordinarily becomes a maximum.

The effect of this charging current flowing through the inductance of the circuit is to increase the receiving-end voltage and therefore to decrease the voltage drop under load. Since the charging current is 2.4 times greater for a frequency of 60 cycles than it is for a frequency of 25 cycles, its effect upon the voltage regulation will be considerably greater at 60 cycles than at 25 cycles. The effect of charging current upon the voltage regulation will also increase as the distance of transmission is increased.

If the circuit were without capacitance, there would be no charging current and consequently the mathematical and the two graphical solutions (impedance methods) which follow under the general heading of "short transmission lines" would all produce accurate results. All circuits, however, have some capacitance, and as the length or the frequency of the circuit increases, these three methods will therefore yield results of increasing inaccuracy. Some engineers consider these impedance methods sufficiently accurate for circuits 20 to 30 miles long while others use them for still longer circuits. To act as a guide, Table J indicates the error in the supply voltage as determined by these impedance methods, for circuits of different lengths corresponding to both 25 and 60 cycle frequencies. These three impedance methods produce practically the same results, and the sending end voltage, as determined by any of these methods, is always slightly high. In other words the effect of the charging current is to reduce the voltage necessary at the sending end, for maintaining a certain voltage at the receiving end of the circuit. The error referred to below for the three methods is expressed in percentage of the receiving end voltage. Thus, for a 30 mile, 25 cycle circuit, the error is 0.04 percent, and for a 30 mile, 60 cycle circuit the error is 0.2 percent. If an error of 0.5 percent is considered permissible, then the Dwight or the Mershon Chart methods, or the corresponding mathematical solution, may be used for 25 cycle circuits up to approximately 125 miles, and for 60 cycles circuits up to approximately 50 miles. Of course these impedance methods may be used for still longer circuits by making proper allowance to compensate for the fundamental error.

DIAGRAM ILLUSTRATING A SHORT TRANSMISSION CIRCUIT

Fig. 16 illustrates the relation between the various elements in short transmission circuits, when the effect of capacitance and leakage is not taken into account. The current flowing in such a circuit meets two opposing e.m.f's.; i.e. of resistance in phase with the current and reactance in lagging quadrature with the current.

The upper part of Fig. 16 illustrates such a circuit schematically and the lower part vectorially. The voltage component required at the sending end to overcome the resistance *IR* of the circuit is indicated in the vector diagram by a short line parallel with the base line *I*, representing the phase of the current. These lines are drawn parallel, since the resistance voltage drop is in phase with the current. The voltage component required at the sending end to overcome the reactance *IX* of the circuit is indicated by a line in quadrature or at right angles, to the phase of the current. The reactance is in quadrature with the current for the reason that the rate of change in the magnetic field (consequently the e.m.f. of self-induction or reactance) surrounding the conductor is greatest when the current is passing through zero. The hypotenuse *IZ* of this small right angle impedance triangle represents the impedance voltage of the circuit. It represents the direction and value of the resulting voltage necessary to overcome the combined effect of the resistance and the reactance of the circuit.

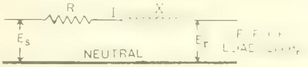
TABLE J

Length of Circuit (Miles)	Error in Percentage of Receiver Voltage	
	25 cycles	60 cycles
20	+0.02	+0.10
30	+0.04	+0.2
50	+0.1	+0.5
100	+0.4	+1.9
200	+1.4	+8.0
300	+3.3	+18.0

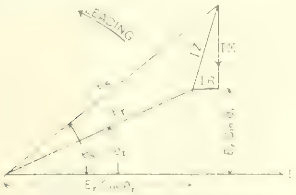
The relative values and phases of the receiving and sending end voltages, and their phase relations with the current I, are also indicated on the vector diagram. This diagram is plotted for a receiving end load based upon 80 percent power-factor lagging. E_s represents the value of the voltage required at the sending end of the circuit to maintain the voltage E_r at the receiving end, when the impedance of the circuit is IZ and the receiving end power-factor is 80 percent lagging. The phase angle θ_s indicates the amount by which the current lags behind the voltage at the sending end; cos θ_s being the power-factor of the load as measured at the sending end. Likewise cos θ_r is the power-factor of the load at the receiving end.

TAPS TAKEN OFF CIRCUIT

Usually the main transmission circuit is tapped and power taken off at one or more points along the circuit. The performance of such a circuit must be calculated by steps thus:—Assume a circuit 200 miles long with 10 000 kw taken off at the middle and 10 000 kw at the receiving end. From the conditions known or assumed at the receiving end, calculate the corresponding sending end conditions, that is the voltage, power and power-factor at the substation in the middle of the circuit. To the calculated value of the actual power in kilowatts add the losses at the substation in the middle of the circuit. Any leading or lagging component in the substation load current must also be added algebraically, in order to determine the power-factor at the sending side of the substation. This will then be the receiving end conditions at the substation in the middle of the circuit, from which the corresponding conditions at the sending end of the circuit may be calculated. If the sending end conditions are fixed, and the receiving end conditions are to be determined, the substation losses will in such case be subtracted in place of added.



EQUIVALENT TRANSMISSION CIRCUIT TO NEUTRAL



VECTOR DIAGRAM OF TRANSMISSION CIRCUIT

FIG. 10—IMPEDANCES [illegible] SHORT TRANSMISSION LINES
Impedance method, capacitance effect not taken into account.

CABLE AND AERIAL LINES IN SERIES COMPOSITE LINES

In some cases it is necessary to place part of a transmission circuit underground, and in other cases it may be desirable to use two or more sizes of conductors in series. The result will be that the circuit constants will be different for the various sections. If the effect of capacitance be neglected, the combined circuit may be treated as a single circuit having a certain total resistance R and a total reactance X.

PROBLEMS

Later a table will be presented listing a large number of transmission circuits from 20 to 500 miles long, at both 25 and 60 cycles operating at from 10 000 to 200 000 volts. These problems are numbered from *1* to *64*. When a reference is made in the following to some problem number it will refer to one of this list of problems.

SYMBOLS

The symbols which will be employed in the following treatment are given below:—

FOR LOAD CONDITIONS

$Kv\text{-}a_r$ = (total) at receiving end.
$Kv\text{-}a_{rn}$ = (one conductor to neutral) at receiving end.
$Kv\text{-}a_s$ = (total) at sending end.
$Kv\text{-}a_{sn}$ = (one conductor to neutral) at sending end.
Kw_r = Kw (total) at receiving end.
Kw_{rn} = Kw (one conductor to neutral) at receiving end.
Kw_s = Kw (total) at sending end.
Kw_{sn} = Kw (one conductor to neutral) at sending end.
E_r = Voltage between conductors at receiving end.
E_{rn} = Voltage from conductors to neutral at receiving end.
E_s = Voltage between conductors at sending end.
E_{sn} = Voltage from conductors to neutral at sending end.
I_r = Current in amperes per conductor at receiving end.
I_s = Current in amperes per conductor at sending end.
$Cos\ \theta_r$ = Power-factor at receiving end.
$Cos\ \theta_s$ = Power-factor at sending end.

FOR ZERO LOAD CONDITIONS

The symbols corresponding to zero load conditions are as indicated above for load conditions with the addition of a sub zero.

THE FUNDAMENTAL OR LINEAR CONSTANTS

The fundamental, or "linear constants" of the circuit for each conductor per unit length are represented as follows:—

r = Linear resistance in ohms per conductor mile (taken from Table II)
x = Linear reactance in ohms per conductor mile (taken from Table IV or V)
b = Linear capacitance susceptance to neutral in ohms per conductor mile (taken from Table IX or X)
g = Linear leakage conductance to neutral in ohms per conductor mile. (This represents the direct escape of active power through the air between conductors and of active power leakage over the insulators. These losses must be estimated for conditions similar to these of the circuit under consideration. For all lines except those of great length and high voltage it is common practice to disregard the effects of leakage or corona loss and to take g as equal to zero.

[illegible] $\sqrt{r^2 + x^2}$

If the length of each conductor of the circuit in unit length is designated as l we have

rl = Total resistance in ohms per conductor = R
xl = Total reactance in ohms per conductor = X
bl = Total susceptance in ohms per conductor to neutral
gl = Total conductance in ohms per conductor to neutral = G

then,

$Z = \sqrt{R^2 + X^2}$ ohms

and, $Y = \sqrt{G^2 + B^2}$ ohms

IR = Voltage necessary to overcome the resistance.
IX = Voltage necessary to overcome the reactance.
IZ = Voltage necessary to overcome the impedance.

METHODS FOR DETERMINING THE CONSTANTS OF THE CIRCUIT

Several different methods for determining the fundamental constants of the circuit are in use. These methods are illustrated below.

Problem—Find the resistance volts IR and the reactance volts IX in percent of delivered volts E_r for the following conditions:—100 kw active power to be delivered at 1000 volts, three-phase, 60 cycles, over three No. 0000 stranded, hard drawn, copper conductors, circuit one mile long, with a symmetrical delta arrangement of conductors, two foot spacing, the temperature being taken as 25 degrees C.

Resistance of one mile of single conductor = 0.277 ohm (from Table II)

Reactance of one mile of single conductor = 0.595 ohm (from Table V)

Method No. 1—When three-phase circuits first came into use, it was customary (and correct), in determining the loss and voltage regulation, to consider them equivalent to two single-phase circuits, each single-phase circuit transmitting one-half the power of the three-phase system. This practice is still followed by some engineers; thus:—

$\frac{50\,000}{1000} = 50$ *amp per conductor for each single-phase circuit.*

$\frac{0.277 \times 2 \times 50}{1000} \times 100 = 2.77\%$ *resistance volts drop of single-phase circuit.*

$\frac{0.595 \times 2 \times 50}{1000} \times 100 = 5.95\%$ *reactance volts drop of single-phase circuit.*

Method No. 2 consists of treating the case as a straight three-phase problem. Thus:

$\frac{100\,000}{1000 \times 1.732} = 57.73$ *amperes per conductor of three-phase circuit.*

$\frac{0.277 \times 1.732 \times 57.73}{1000} \times 100 = 2.77\%$ *resistance volts drop of three-phase circuit.*

$\frac{0.595 \times 1.732 \times 57.73}{1000} \times 100 = 5.95\%$ *reactance volts drop of three-phase circuit.*

Method No. 3 consists in assuming one-third the total power transmitted over one conductor with neutral or ground return (resistance and reactance of return being taken as zero). Such an equivalent circuit is shown by diagram in the upper part of Fig. 16. Thus the circuit constants for the above problem would be determined as follows:—

Power per phase $= \frac{100\,000}{3} = 33\,333$ *watts*

Volts to neutral = 1000 × 0.5774 *or* 577.4 *volts.*

$\frac{33\,333}{577.4} = 57.74$ *amperes per conductor; (same as for method No. 2)*

$\frac{0.277 \times 57.74}{577.4} \times 100 = 2.77\%$ *resistance volts drop of three-phase circuit.*

$\frac{0.595 \times 57.74}{577.4} \times 100 = 5.95\%$ *reactance volts drop of three-phase circuit.*

It will be seen that all three methods produce the same results. *Method No. 3* seems the most readily adaptable to various kinds of transmission systems and will be used exclusively in the treatment of the problems which will follow.

APPLICATION OF THE TABLES

Numerous tables of constants, charts, etc., have been presented, and a few more will follow. Chart II plainly indicates the application of these tables, etc. to the calculation of transmission circuits and the sequence in which they should be consulted.

GRAPHICAL VS. MATHEMATICAL SOLUTIONS

At the time of the design of a transmission circuit the actual maximum load or power-factor of the load that the circuit will be called upon to transmit is seldom known. An unforseen development leading to an increased demand for electrical energy may result in a greatly increased load to be transmitted. The actual length of a circuit (especially when located in a hilly or rolling country) is never known with mathematical accuracy. Moreover, the actual resistance of the conductors varies to a large extent with temperature variations along the circuit.

When it is considered that there are so many indeterminate variables which vitally affect the performance of a transmission circuit, it would seem that a comparatively long and highly mathematical solution for determining the exact performance, necessarily based upon rigid assumptions, is hardly justified. In many cases the economic loss in transmission will determine the size of conductors and, if the circuit is very long, synchronous machinery is likely to be employed for controlling the voltage.

Mathematical solutions have one very important virtue, in that they provide an entirely different but parallel route in the solution of such problems, and therefore are valuable as a check against serious errors in the results obtained by the more simple graphical solutions.

In the following treatment, simple but highly accurate graphical solutions will be first presented, for determining the performance not only of short transmission lines, but also for long lines. For short lines the Dwight and the Mershon charts will be used. For long lines, where the effect of capacitance must be accurately accounted for, the Wilkinson Charts, supplemented with vector diagrams will be used. These three forms of graphical solutions will, when correctly applied to any power transmission problem, produce results in which the error will be much less than that due to irregularities in line construction and inaccurate assumptions of circuit constants. These three graphical solutions will in each case be followed by mathematical solutions. In the case of short lines the usual formulas employing trigonometric functions will be employed, and in the case of long lines the convergent series, and two different forms of hyperbolic solutions will be employed.

GRAPHICAL SOLUTION

When the receiving end load conditions, that is, the voltage, the load and the power-factor are known, the *IR* volts required to overcome the resistance and the *IX* volts required to overcome the reactance of the circuit, may be readily calculated.

On a piece of plain paper or cross-section paper divided into tenths, a vector diagram of the current and of the various voltage drops of the circuit may be laid out to a convenient scale. Whichever kind of paper is used, the procedure will be as in the following example.

Single-Phase Problem—Find the voltage at the sending end of a single-phase circuit 16 miles long, consisting of two stranded, hard drawn No. 0000 copper conductors spaced three feet apart. Temperatures taken as 25 degrees C. Load conditions at receiving end assumed as 4000 kv-a (3200 kw at 80 percent power-factor lagging) 20 000 volts, single-phase, 60 cycles

$$Kv\text{-}a_{rn} = \frac{4000}{2} = 2000 \textit{ kv-a to neutral.}$$

$$E_{rn} = \frac{20\,000}{2} = 10\,000 \textit{ volts to neutral.}$$

$$I_r = \frac{2\,000\,000}{10\,000} = 200 \textit{ amperes per conductor.}$$

The fundamental constants per conductor are:—

$$R = 16 \times 0.277 \textit{ (from Table II)} = 4.432 \textit{ ohms}$$

$$X = 16 \times 0.644 \textit{ (from Table V)} = 10.304 \textit{ ohms}$$

and $IR = 200 \times 4.432 = 886$ *volts resistance drop*

$$= \frac{886}{10\,000} \times 100 = 8.86 \textit{ percent}$$

$$IX = 200 \times 10.304 = 2061 \textit{ volts reactance drop}$$

$$= \frac{2061}{10\,000} \times 100 = 20.61 \textit{ percent}$$

Having determined the above values a vector diagram may be made as follows:—

Draw an arc quadrant having a radius of 10 000 (the receiving end voltage to neutral) to some convenient scale, as shown in Fig. 17. The radius which represents the base, or horizontal line will be assumed as representing the phase of the current at the receiving end of the circuit. Divide this base line into ten equal parts. These ten divisions will then correspond to loads of corresponding power-factors. Since a load has been assumed having a power-factor of 80 percent lagging, draw a vertical line from the 0.8 division on the base line, until it intersects the arc of the circle. From this point of intersection draw a line to the right and parallel with the base line. To the same scale as that plotted for the receiver voltage (10 000) measure off to the right 886 volts to *D*. This is the voltage which, as determined above is required to overcome the resistance of one conductor of the circuit. It is sometimes stated as the voltage consumed by the line resistance. It will be noted that this voltage drop is in phase with the current at the receiving end. From this point lay off vertically, and to the same scale, 2061 volts which is, as determined above, the volts necessary to overcome the reactance of one conductor of the circuit. This is sometimes stated as the voltage consumed by the line reactance. Connect this last point by a straight

CHART II.—APPLICATION OF TABLES TO SHORT TRANSMISSION LINES

(EFFECT OF CAPACITANCE NOT TAKEN INTO ACCOUNT) OVER HEAD BARE CONDUCTORS

Starting with the kv-a., voltage and power-factor at the receiving end known.

QUICK ESTIMATING TABLES XII TO XXI INC.

From the quick estimating table corresponding to the voltage to be delivered, determine the size of the conductors corresponding to the permissible transmission loss.

HEATING LIMITATION—TABLE XXIII

If the distance of transmission is short and the amount of power transmitted very large there is a possibility of overheating the conductors—to guard against such overheating the carrying capacity of the conductors contemplated should be checked by this table.

CORONA LIMITATION—TABLE XXII

If the transmission is at 30 000 volts, or higher, this table should be consulted to avoid the employment of conductors having diameters so small as to result in excessive corona loss.

RESISTANCE—TABLES I AND II

From one of these tables obtain the resistance per unit length of single conductor corresponding to the maximum operating temperature—calculate the total resistance for one conductor of the circuit—if the conductor is large (250 000 circ. mils or more) the increase in resistance due to skin effect should be added.

I^2R TRANSMISSION LOSS

Calculate the I^2R loss of one conductor by multiplying its total resistance by the square of the current—to obtain the total loss multiply this result by the number of conductors of the circuit.

REACTANCE—TABLES IV AND V

From one of these tables obtain the reactance per unit length of single conductor. Calculate the total reactance for one conductor of the circuit. If the reactance is excessive (20 to 30 percent reactance volts will in many cases be considered excessive) consult Table VI or VII. Having decided upon the maximum permissible reactance the corresponding resistance may be found by dividing this reactance by the ratio value in Table VI or VII. When the reactance is excessive, it may be reduced by installing two or more circuits and connecting them in parallel, or by the employment of three conductor cables. Using larger conductors will not materially reduce the reactance. The substitution of a higher transmission voltage, with its correspondingly less current, will also result in less reactance.

GRAPHICAL SOLUTION

A simple graphical solution, as described in the text, may be made by which the kv-a, the voltage and the power-factor at the sending end of the circuit may be determined graphically. Or the voltage at the sending end may be determined graphically by the use of either the Dwight or the Mershon chart. With the Mershon chart the power-factor at the sending end may be read directly from the chart.

MATHEMATICAL SOLUTION

As a precaution against errors the results obtained graphically should be checked by a mathematical solution, in cases where accuracy is essential.

line with the center *E* of the arc. The length of this line *ES* represents the voltage to neutral at the sending end which, for this problem, is 11 998 volts. The distance this line extends beyond the arc represents the drop in voltage for one conductor of the circuit. The voltage drop for this problem is $\frac{1998}{10\,000} \times 100 = 19.98$ percent of the receiving end voltage.

The phase difference between the current and the voltage at the receiver end is $\theta_r = 36° 52'$. This is the angle whose cosine is 0.8 corresponding to a power-factor at the receiving end of 80 percent. Likewise the phase difference between the receiving end current and the sending end voltage is $\theta_s = 42° 13'$ corresponding to a power-factor at the supply end of 74.06 percent. The difference in these two phase angles (5° 21′) represents the difference in the phase of the voltages at the sending and receiving ends of the circuit. The power-factor at the sending end of the circuit may be readily obtained by dropping a vertical line down from the point where the line representing the sending end voltage *ES* intersects the arc of the circle, to the base line representing the phase of the receiving end current. Such a line will correspond to a power-factor of 74.06 percent. This assumption that the vector representing the direction of the receiving end current also represents the direction of the sending end current is upon the basis that the circuit is without capacitance. It, therefore, is permissible only with short lines.

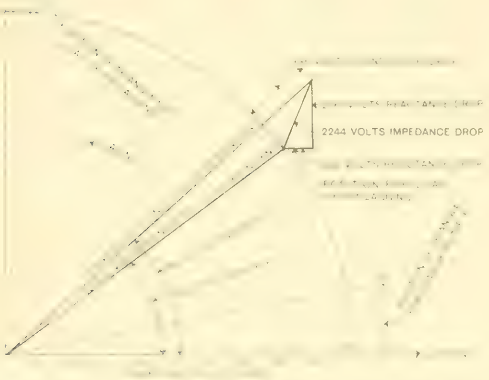


FIG. 17—GRAPHICAL SOLUTION FOR A SHORT TRANSMISSION LINE
Capacitance effect not taken into account.

In Fig. 17 the location of the impedance triangle is also indicated (by broken lines) in positions corresponding to a receiving end load of 100 percent power-factor; and also for a receiving end load of zero lagging power-factor. It is interesting to note that in the case of 100 percent power-factor the resistance drop (at right angle to the arc) has a maximum effect upon the voltage drop; whereas the reactance drop (nearly parallel with the arc) has a minimum effect upon the voltage drop. At zero lagging power-factor load just the reverse is true; namely the resistance drop is nearly parallel with the arc and causes a minimum voltage drop, while the reactance is at right angles and produces a maximum effect upon the voltage drop.

VOLTAGE AT SENDING END AND LOAD AT RECEIVING END FIXED

In cases of feeders to be tapped into main transmission circuits, the voltage at the sending end is usually fixed. It may be desired to determine what the voltage will be at the receiving end corresponding to a given load. This may be obtained graphically as follows:—

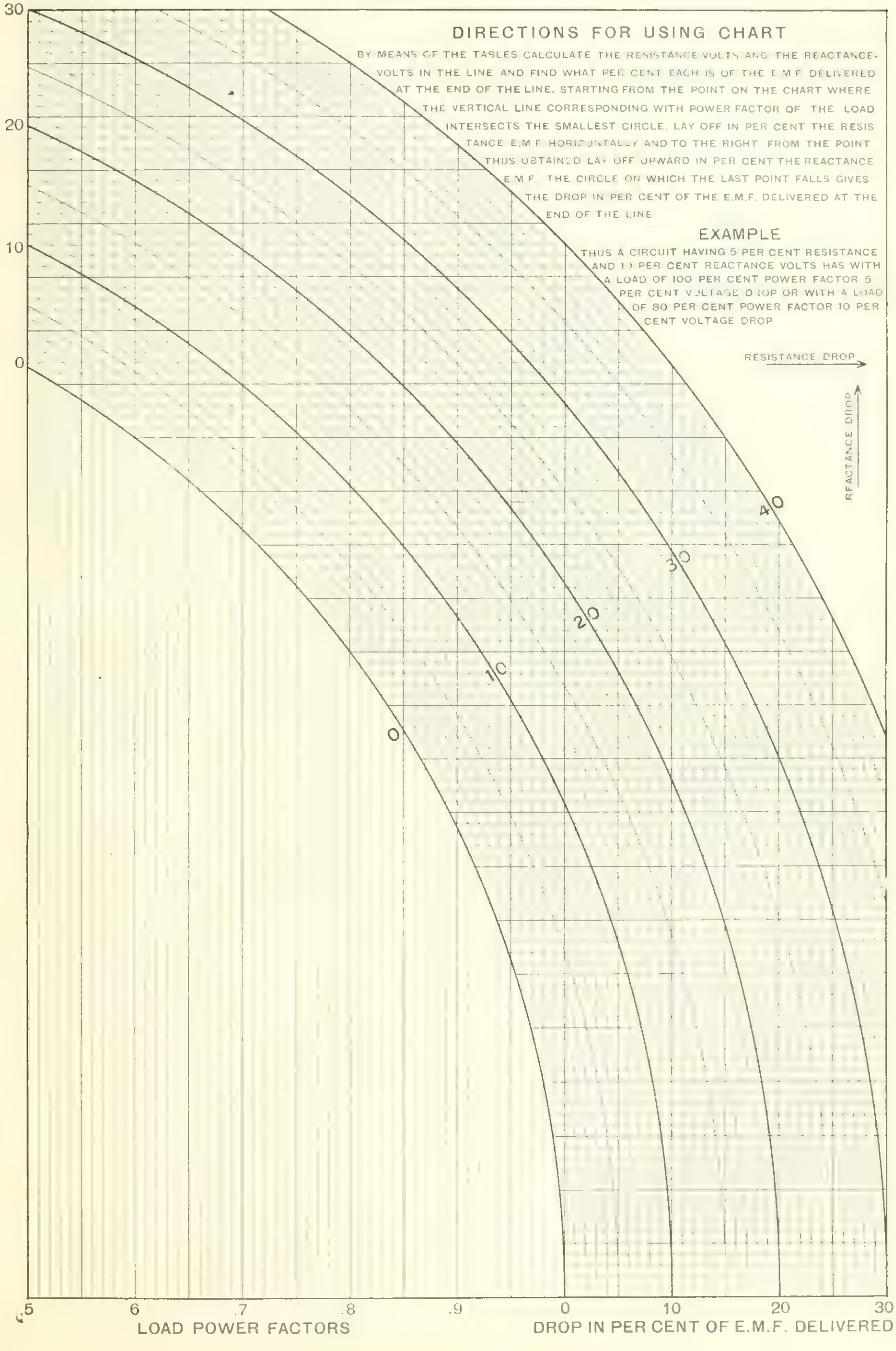
Draw a horizontal line which will be assumed to represent the phase of the current. (Fig. 17) Since the power-factor of the load at the receiving end is known, the angle whose cosine corresponds may be obtained from Table *K*. This angle represents the phase relation between the current and the voltage at the receiving end of the circuit. For the problem illustrated by Fig. 17 this angle is 36° 52′, corresponding to a power-factor of 80 percent. Having determined this angle, draw a second radial line intersecting the current vector at the angle corresponding to the receiving end load power-factor. This second line will then represent the direction of the voltage at the receiving end of the circuit. If the load power-factor is lagging, this line will be in the forward direction, and if the load power-factor is leading it will be in the backward direction from the current vector. Now with the intersection of the current and voltage vectors as a center, draw an arc of a circle to some suitable scale, representing the voltage at the sending end. Calculate the voltage necessary to overcome the resistance, and also that necessary to overcome the reactance of the circuit.

Draw a right angle impedance triangle to the same scale, using the resistance volts as a base. Cut out the impedance triangle to its exact size. Keeping the base of the triangle (resistance voltage) in a horizontal position (parallel with the current vector) move the triangle over the diagram in such a manner that its apex follows the arc of the circle representing the numerical value of the voltage at the sending end. Move the triangle up or down until a position is found where it makes connection with the vector representing the voltage at the receiving end. This is then the correct position for the impedance triangle, and the receiving end voltage may be scaled off.

[illegible]

The above graphical solution is that employed in the well known chart which Mr. Ralph D. Mershon early presented to the electrical profession, and which is reproduced as Chart III. The Mershon Chart is simply a diagram on cross-section paper with vertical and horizontal subdivisions each representing one percent of receiving end voltage. On this chart a number of concentric arcs are drawn, representing voltage drops up to 40 percent. After the reactance and the resistance volts have been calculated and expressed in per-

CHART III—MERSHON CHART



DIRECTIONS FOR USING CHART

BY MEANS OF THE TABLES CALCULATE THE RESISTANCE VOLTS AND THE REACTANCE-VOLTS IN THE LINE AND FIND WHAT PER CENT EACH IS OF THE E.M.F. DELIVERED AT THE END OF THE LINE. STARTING FROM THE POINT ON THE CHART WHERE THE VERTICAL LINE CORRESPONDING WITH POWER FACTOR OF THE LOAD INTERSECTS THE SMALLEST CIRCLE, LAY OFF IN PER CENT THE RESISTANCE E.M.F. HORIZONTALLY AND TO THE RIGHT. FROM THE POINT THUS OBTAINED LAY OFF UPWARD IN PER CENT THE REACTANCE E.M.F. THE CIRCLE ON WHICH THE LAST POINT FALLS GIVES THE DROP IN PER CENT OF THE E.M.F. DELIVERED AT THE END OF THE LINE

EXAMPLE

THUS A CIRCUIT HAVING 5 PER CENT RESISTANCE AND 10 PER CENT REACTANCE VOLTS HAS WITH A LOAD OF 100 PER CENT POWER FACTOR 5 PER CENT VOLTAGE DROP OR WITH A LOAD OF 80 PER CENT POWER FACTOR 10 PER CENT VOLTAGE DROP cent of E_r the impedance triangle is traced upon the chart and the voltage drop in percentage of E_r is read directly as indicated by the directions. All values on the chart are expressed in percent of the receiving end voltage.

Single-Phase Problem—Taking the resistance voltage as 8.86 percent and the reactance voltages 20.61 percent of the receiving end voltage, for the above single-phase problem, (Fig. 17) and tracing these values upon the Mershon Chart for a receiving end load of 80 percent power-factor lagging, the voltage drop is determined as 19.9 percent. The calculated value being 19.98 percent, the error by the chart is seen to be negligible.

WHEN THE SENDING END CONDITIONS ARE FIXED

When the conditions at the sending end are fixed and those at the receiving end are to be determined, the solving of the problem by the Mershon Chart is more complicated. In such cases, it is usual to estimate what the probable receiving end condition will be. From these estimated receiving end conditions, determine by the chart the corresponding sending end conditions. If the conditions as determined by this assumption are materially different from the known conditions, another assumption should be made. The corresponding sending end conditions should then be checked with the known conditions. Several such trials will usually be necessary to solve such problems.

GRAPHICAL SOLUTION BY THE DWIGHT CHART

Mr. H. B. Dwight has worked up a straight line chart, shown as Chart IV, in which the resistance and the reactance of the circuit have been taken into account through the medium of spacing lines marked for various sizes of conductors.* The use of this chart does not, therefore, require the calculation of the resistance and reactance or the use of tables of such constants. The Dwight Chart is also constructed so as to be applicable to loads of leading as well as to loads of lagging power-factors, whereas the Mershon chart, as generally constructed, is applicable to loads of lagging power-factor only. However the Mershon Chart can be made applicable for the solving of problems of leading as well as lagging power-factor loads by extending it through the lower right-hand quadrant. The application of synchronous condensers frequently gives rise to loads of leading power-factor. The Dwight Chart is well adapted to the solution of such circuits. Still another feature of this chart is that formulas are given which take capacitance effect into account with sufficient accuracy for circuits with a length up to approximately 100 miles.

Single-Phase Problem—Find the voltage at the sending end of a single-phase circuit 16 miles long, consisting of two stranded, hard-drawn, No. 0000 copper conductors, spaced three feet apart. Temperature taken as 25 degrees C. Load condition at receiving end assumed as 4000 kv-a (3200 kw at 80 percent power-factor lagging) 20 000 volts single-phase, 60 cycles.

From Table II the resistance of No. 0000 stranded, hard-drawn, copper conductors at 25 degrees C. is found to be 0.277 ohm per wire per mile. Lay a straight edge across the Dwight Chart from the resistance value per mile 0.277 (as read on the lower half of the vertical line to the extreme right) to the spacing of three feet for copper conductors and 60 cycles at the extreme left. Along this straight edge read factor $V = 0.62$, corresponding to a lagging power-factor of 80 percent. This factor V is equivalent to the change in receiving end voltage per total ampere per mile of circuit, due to the line impedance.

It will be noted that opposite the resistance values (extreme right vertical line) is placed the corresponding sizes of copper and aluminum conductors on the basis of a temperature of 20 degrees C. If the temperature is assumed to be 20 degrees C. it will not be necessary to consult a table of resistance values. In such a case, the straight edge would simply be placed over the division of the vertical resistance line corresponding to the size and material of conductors. Marking a resistance value on this vertical line makes the chart adaptable to resistance values corresponding to conductors at any temperature. Had the power factor been leading, in place of lagging, the corresponding resistance point would have been located on the upper half of the vertical resistance line.

Continuing following the directions on the chart for short lines, we obtain the following. Since the circuit is single-phase, use $2\,V = 1.24$

$$\textit{Voltage drop in percent of } E_r = \frac{100\,000 \times 4000 \times 16 \times 1.24}{20\,000^2}$$
$$= 19.84 \textit{ percent}$$

The voltage drop, as calculated mathematically, is 19.98 percent representing an error of 0.14 percent by the chart.

Three-Phase Problem (No. 33)—Find the voltage at the sending end of a three-phase circuit, 20 miles long, consisting of three No. 0000 stranded, hard-drawn, copper conductors, spaced three feet apart in a delta arrangement. Temperature taken as 25 degrees C. Load conditions at receiving end assumed as 1300 kv-a (1040 kw at 80 percent power factor lagging) 10 000 volts, three-phase, 60 cycles.

From Table II, the resistance per wire per mile is again found to be 0.277 ohm and since the spacing and frequency are both the same as in the case of the above single-phase problem, we again obtain $V = 0.62$. The voltage drop in percent of E_r is therefore

$$\frac{100\,000 \times 1300 \times 20 \times 0.62}{10\,000^2} = 16.12 \textit{ percent}$$

The voltage drop as calculated mathematically is 16.16 percent, representing an error of 0.04 percent.

CAPACITANCE

In long circuits the effect of capitance is to decrease the voltage drop, or increase the voltage rise, as

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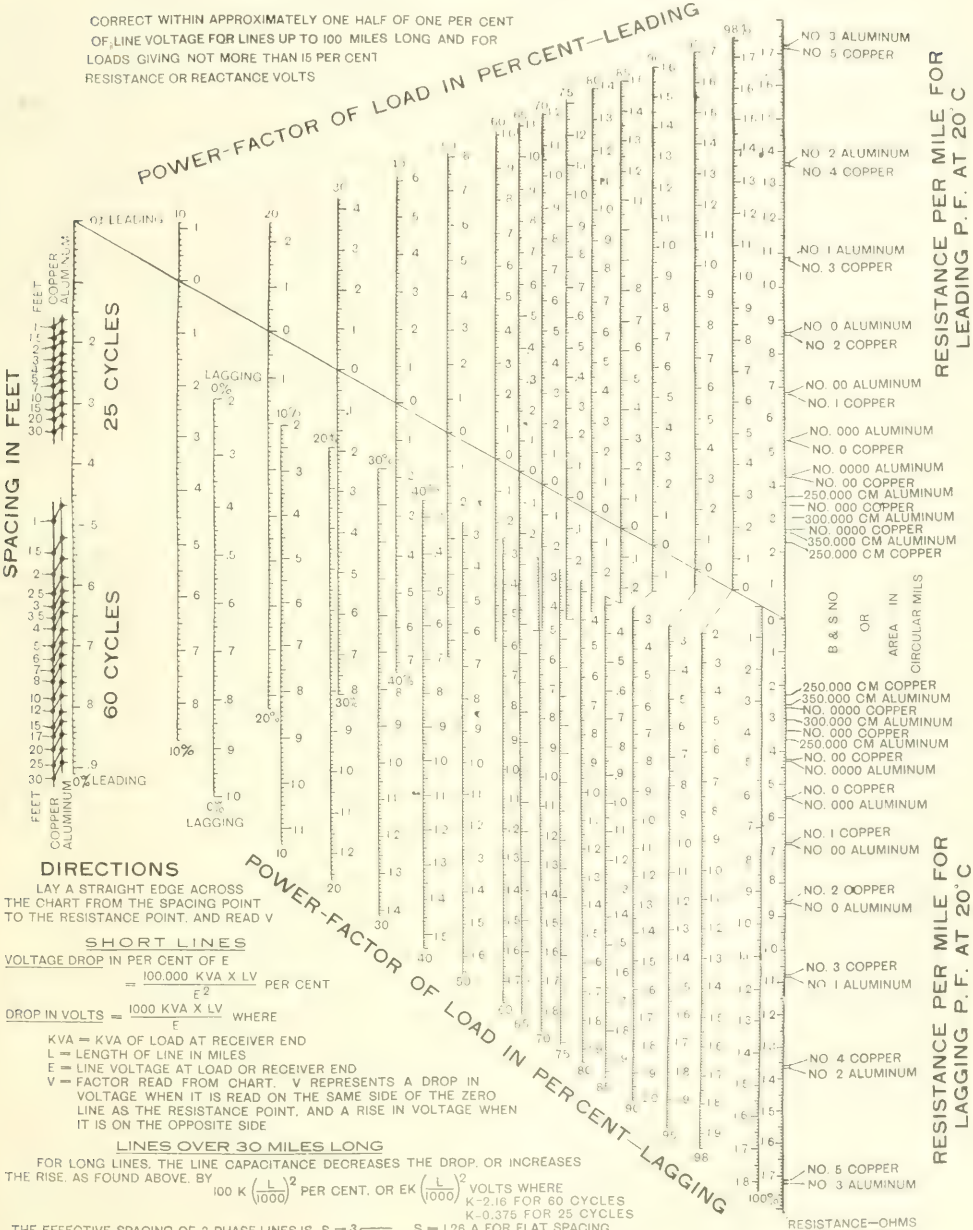
*The basis of the construction of this chart is described in the JOURNAL for July, 1915, p. 306.

CHART IV
DWIGHT CHART

FOR DETERMINING THE VOLTAGE REGULATION OF TRANSMISSION CIRCUITS CONTAINING CAPACITANCE



CORRECT WITHIN APPROXIMATELY ONE HALF OF ONE PER CENT OF LINE VOLTAGE FOR LINES UP TO 100 MILES LONG AND FOR LOADS GIVING NOT MORE THAN 15 PER CENT RESISTANCE OR REACTANCE VOLTS

DIRECTIONS

LAY A STRAIGHT EDGE ACROSS THE CHART FROM THE SPACING POINT TO THE RESISTANCE POINT, AND READ V

SHORT LINES

VOLTAGE DROP IN PER CENT OF E

$$= \frac{100.000\ \text{KVA} \times \text{LV}}{E^2} \text{ PER CENT}$$

DROP IN VOLTS $= \frac{1000\ \text{KVA} \times \text{LV}}{E}$ WHERE

KVA = KVA OF LOAD AT RECEIVER END
L = LENGTH OF LINE IN MILES
E = LINE VOLTAGE AT LOAD OR RECEIVER END
V = FACTOR READ FROM CHART. V REPRESENTS A DROP IN VOLTAGE WHEN IT IS READ ON THE SAME SIDE OF THE ZERO LINE AS THE RESISTANCE POINT, AND A RISE IN VOLTAGE WHEN IT IS ON THE OPPOSITE SIDE

LINES OVER 30 MILES LONG

FOR LONG LINES, THE LINE CAPACITANCE DECREASES THE DROP, OR INCREASES THE RISE, AS FOUND ABOVE, BY $100\ K \left(\frac{L}{1000}\right)^2$ PER CENT, OR $EK \left(\frac{L}{1000}\right)^2$ VOLTS WHERE

K-2.16 FOR 60 CYCLES
K-0.375 FOR 25 CYCLES

THE EFFECTIVE SPACING OF 3 PHASE LINES IS $S = \sqrt[3]{ABC}$ $S = 1.26$ A FOR FLAT SPACING

THE ABOVE EQUATIONS ARE FOR 2 AND 3 PHASE LINES
FOR SINGLE PHASE USE 2 V IN PLACE OF V

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will be explained later. The Dwight and Mershon charts do not recognize the effect which capacitance has upon the voltage drop. In the lower left hand corner of the Dwight Chart, however, there is placed a formula by which a correction may be applied to the voltage drop as given by the chart. This correction accounts for the effect of the charging current (resulting from capacitance) quite accurately, provided the circuit is not too long or the frequency too high. The application of this corrective factor will be evident from the following problem.

TABLE K—COSINES, SINES AND TANGENTS

ANGLE	COS θ P F	SIN θ	TAN θ
0° 00′	1.000	0.0000	0.0000
8° 06′	0.990	0.1409	0.1423
11° 28′	0.980	0.1988	0.2028
14° 04′	0.970	0.2430	0.2506
16° 15′	0.960	0.2798	0.2915
18° 11′	0.950	0.3120	0.3285
19° 56′	0.940	0.3410	0.3627
21° 33′	0.930	0.3673	0.3949
23° 04′	0.920	0.3918	0.4258
24° 29′	0.910	0.4144	0.4554
25° 50′	0.900	0.4357	0.4841
27° 07′	0.890	0.4558	0.5121
28° 21′	0.880	0.4748	0.5396
29° 32′	0.870	0.4929	0.5665
30° 41′	0.860	0.5103	0.5934
31° 47′	0.850	0.5267	0.6196
32° 51′	0.840	0.5424	0.6457
33° 54′	0.830	0.5577	0.6720
34° 55′	0.820	0.5721	0.6976
35° 54′	0.810	0.5864	0.7239
36° 52′	0.800	0.6000	0.7499
37° 48′	0.790	0.6129	0.7757
38° 44′	0.780	0.6257	0.8021
39° 38′	0.770	0.6379	0.8283
40° 32′	0.760	0.6499	0.8551
41° 24′	0.750	0.6613	0.8816
42° 16′	0.740	0.6726	0.9089
43° 06′	0.730	0.6833	0.9358
43° 56′	0.720	0.6938	0.9634
44° 45′	0.710	0.7040	0.9913
45° 34′	0.700	0.7141	1.0199
46° 22′	0.690	0.7238	1.0489
47° 09′	0.680	0.7331	1.0780
47° 55′	0.670	0.7422	1.1074
48° 42′	0.660	0.7513	1.1383
49° 27′	0.650	0.7598	1.1688
50° 12′	0.640	0.7683	1.2002
50° 57′	0.630	0.7766	1.2327
51° 41′	0.620	0.7846	1.2655
52° 24′	0.610	0.7923	1.2985
53° 07′	0.600	0.8000	1.3327
53° 50′	0.590	0.8073	1.3680
54° 32′	0.580	0.8145	1.4037
55° 14′	0.570	0.8215	1.4406
55° 56′	0.560	0.8284	1.4788
56° 37′	0.550	0.8350	1.5175
57° 18′	0.540	0.8415	1.5577
57° 59′	0.530	0.8479	1.5993
58° 40′	0.520	0.8542	1.6426
59° 20′	0.510	0.8601	1.6864
60° 00′	0.500	0.8660	1.7320
60° 39′	0.490	0.8716	1.7783
61° 18′	0.480	0.8771	1.8265
[illegible]	0.470	0.8825	1.8768

Three-Phase Problem (No. 45)—Find the voltage at the sending end of a three phase circuit, 100 miles long, consisting of three No. 0000, stranded, hard-drawn copper conductors, spaced nine feet apart in a delta arrangement. Temperature assumed as 25 degrees C. Load conditions at receiving end assumed as 22 000 kv-a, 80 percent power-factor lagging, 88 000 volts, 60 cycles.

From Table II the resistance is found to be 0.277 ohm per mile. From Dwight Chart read V = *0.70*. Then, the voltage drop in percent of E_r, if the line were short, would be,

$$\frac{100\,000 \times 22\,000 \times 100 \times 0.70}{88\,000} = 19.89 \text{ percent}$$

From directions on the Dwight chart for circuits over 30 miles long, the charging current of this circuit is found to be such as to decrease the voltage drop under load conditions or to increase the voltage at zero load by the amount of $100 \times 2.16\left(\frac{100}{1000}\right)^2 = 2.16$ percent. Hence the voltage at the sending end, under load conditions, will be *19.89 — 2.16 = 17.73* percent. The actual result as calculated rigorously is *17.94* percent. Thus the error by the Dwight graphical solution is approximately *0.21* percent.

If the power-factor of the load is assumed as 100 percent (problem 46) in place of 80 percent lagging, we get $V = 0.33$ and find the error for the Dwight graphical solution of this 100 mile, 60 cycle circuit to be approximately *0.75* percent. It should be noted, however, that the reactance volts are in this case *22* percent of the receiving end voltage.

SENDING END CONDITIONS FIXED

When the sending end conditions are fixed, a different form of solution must be employed to determine the size of conductors corresponding to a given voltage drop. In such cases, the Dwight Chart is particularly applicable. To use the chart for the solution of such problems proceed as follows. First V is calculated by means of the formulas on the chart, and then a straight edge is placed through V (on the line corresponding to the power-factor of the load) and the point for the spacing and frequency to be used, and the required size of conductor can be seen at a glance on the resistance scale at the right. To make this application of the chart clear, the following is given,—

$$\text{Voltage drop in percent} = \frac{100\,000 \times Kv\text{-}a \times L \times V}{E^2} \qquad (28)$$

Hence

$$V = \frac{\text{Voltage drop in percent} \times E^2}{100\,000\ Kv\text{-}a \times L} \qquad (29)$$

Applying (29) to the above problem No. 33 we get

$$V = \frac{16.12 \times 10\,000^2}{100\,000 \times 1\,300 \times 20} = 0.62$$

Following the above directions, the resistance per mile is found to be 0.277 ohm and the corresponding size of conductor No. 0000 copper.

MATHEMATICAL SOLUTION

In order to check any one, or all of the above described graphical methods, a complete mathematical solution may be made by applying the various trigonometrical formulas, Fig. 18, to the values of the problem under consideration. These formulas have been arranged to meet the conditions of loads of either lagging or leading power-factors, and for conditions fixed at either the receiving or the sending ends.

There are numerous problems requiring a solution where the voltage at the sending end, and the kilowatts and the power-factor of the load at the receiving end are fixed. In such cases it is required to determine the corresponding receiving end voltage. This determination can be made mathematically, but such a solution is tedious, since the formulas applying to such cases are cumbersome. Formulas are given at the bottom of Fig. 18 which may be applied to such problems. Time and labor may, however, be saved in solving such problems by the employment of a cut-and-try method usually used in such cases, as follows:—

Assume what the voltage drop will be, corresponding to the size of conductors likely to be used. On the basis of this assumption the receiving end voltage is fixed; thus, all of the receiving end conditions are assumed to be fixed. The corresponding sending end voltage is then readily determined by one of the graphical methods described. If the sending end voltage thus determined is found to be materially different from the fixed sending end voltage, another trial, based upon a different receiving end voltage, will probably suffice.

Single-Phase Problem—Find the characteristics of the load at the sending end of a single-phase circuit, 16 miles long, consisting of two stranded, hard drawn, copper conductors, spaced three feet apart; temperature taken as 25 degrees C.; load conditions at receiving end assumed as 4000 kv-a (3200 kw at 80 percent power-factor lagging) 20 000 volts, 60 cycles; transmission loss to be approximately ten percent.

Following the procedure given in Chart II, consult Quick Estimating Table XVII for a delivered voltage of 20 000. Since the conditions of the above problem are a power-factor of 80 percent, and a temperature 25 degrees C, the corresponding kv-a values are as indicated at the head of the table on the basis of 10.8 percent loss in transmission for a three-phase circuit. For a single-phase circuit the corresponding values will be one-half the table values. Thus the 4 000 kv-a single phase circuit of the problem is equivalent to 8000 kv-a, three-phase on the table. From the table, it is seen that for a distance of 16 miles 7810 kv-a, three-phase can be transmitted over No. 0000 conductors with a loss of 10.8 percent. 7810 kv-a is near enough to 8000 kv-a, and the loss of 10.8 percent is near enough to an assumed loss of ten percent, so we decide that No. 0000 copper conductors come nearest to the proper size to meet the conditions of the problem. The loss with No. 0000 conductors will be $\frac{8000}{7810} \times 10.8 = 11.06$ percent, as will be shown later.

Table XXIII indicates that there will be no overheating of this size of conductor.

Table XXII indicates that 20 000 volts is too low to result in corona loss with No. 0000 conductors, at any reasonable altitude. Then,—

$$Kv\text{-}a_{rn} = \frac{4000}{2} = 2000 \textit{ kv-a to neutral}$$

$$Kw_{rn} = \frac{3200}{2} = 1600 \textit{ kw to neutral.}$$

$$E_{rn} = \frac{20\,000}{2} = 10\,000 \textit{ volts to neutral}$$

$$I_r = \frac{2\,000\,000}{10\,000} = 200 \textit{ amperes per conductor.}$$

The resistance per conductor is

$R = 16 \times 0.277$ (*from Table II*) $= 4.432$ *ohms.*

The reactance per conductor is

$X = 16 \times 0.644$ (*from Table IV*) $= 10.304$ *ohms.*

and $IR = 200 \times 4.432 = 866$ *volts, resistance drop*

$$= \frac{886}{10\,000} \times 100 = 8.86 \textit{ percent}$$

$IX = 200 \times 10.304 = 2061$ *volts, reactance drop*

$$= \frac{2061}{10\,000} \times 100 = 20.61 \textit{ percent}$$

$$E_{sn} = \sqrt{(10\,000 \times 0.8 + 866)^2 + (10\,000 \times 0.6 + 2061)^2}$$
$$= 11\,008 \textit{ volts to neutral} \ldots\ldots\ldots\ldots\ldots\ldots (30)$$

$$\theta_s = \tan^{-1}\left(\frac{(10\,000 \times 0.6) + 2061}{(10\,000 \times 0.8) + 886}\right) = 42^\circ\ 13' \ldots\ldots (31)$$

$$\textit{Percent } PF_s = (\textit{Cos } 42^\circ\ 13') \times 100 = 74.06 \textit{ percent} \ldots (32)$$

$$Kv\text{-}a_{sn} = \frac{200 \times 11\,008}{1000} = 2390.6 \textit{ kv-a per conductor} \ldots\ldots (33)$$

$$Kw_{sn} = 2390.6 \times 0.7406 = 1777.1 \text{ kw per conductor} \ldots\ldots (34)$$

$$\textit{Percent voltage drop} = \frac{11\,008 - 10\,000}{10\,000} \times 100 = 10.08 \textit{ percent}$$
$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (46)$$

$$\textit{Transmission loss} = \frac{(200)^2 \times 4.432}{1000} = 177.28 \textit{ kw per conductor}$$
$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (47)$$

$$\textit{Percent transmission loss} = \frac{177.28 \times 2}{3200} \times 100 = 11.08 \textit{ percent}$$
$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (48)$$

Three-Phase Problem (No. 33)—Find the characteristics of the load at the sending end of a three-phase circuit 20 miles long, consisting of three stranded, hard-drawn, copper conductors, spaced in a three foot delta. Temperature taken as 25 degrees C. Load conditions at receiving end assumed as 1300 kv-a. (1040 kw at 80 percent power-factor lagging) 10 000 volts, 60 cycles; transmission loss not to exceed ten percent.

Following the procedure given in Chart II, the following results are obtained:—

Consult Table XV for a delivered voltage of 10 000 volts. Since the conditions of the above problems are, power factor of load 80 percent, temperature 25 degree C. the corresponding three-phase kv-a values of the table are on the basis of 10.8 percent loss in transmission. From Table XV it is seen that 1240 kv-a, three-phase can be transmitted over No. 000 conductors, or 1560 kv-a., three-phase over No. 0000 conductors at 10.8 percent loss. Since the loss for the problem is not to exceed ten percent and 1300 kv-a is to be transmitted, we will select No. 0000 conductors. The loss for these conductors will therefore be $\frac{1300}{1560}$ of 10.8, or nine percent as will be shown later.

Table XXIII indicates that there will be no overheating of this size of conductor when carrying 1300 kv-a, three phase.

Table XXII indicates that 10 000 volts is too low to result in corona loss with No. 0000 conductors at any reasonable altitude. Then:—

$$Kv\text{-}a_{rn} = \frac{1300}{3} = 433.33 \textit{ kv-a to neutral}$$

$$Kw_{rn} = \frac{1040}{3} = 346.6 \textit{ kw to neutral.}$$

$E_{rn} = \frac{10\,000}{1.732} = 5774$ *volts to neutral.*

$I_r = \frac{433\,333}{5774} = 75.05$ *amperes per conductor.*

The resistance per conductor is,—

$R = 20 \times 0.277$ *(from Table II)* $= 5.54$ ***ohms.***

The reactance per conductor is,—

$X = 20 \times 0.644$ *(from Table V)* $= 12.88$ *ohms.*

and

$IR = 75.05 \times 5.54 = 415.8$ *volts, resistance drop.*

$\frac{415.8}{5774} \times 100 = 7.20$ *percent.*

$IX = 75.05 \times 12.88 = 966.6$ *volts, reactance drop.*

$\frac{966.6}{5774} \times 100 = 16.74$ *percent*

$E_{sn} = \sqrt{(5774 \times 0.8 + 415.8)^2 + (5744 \times 0.6 + 966.6)^2} = 6707$ *volts to neutral* .... (30)

$\theta_s = \tan^{-1}\left(\frac{5774 \times 0.6 + 966.6}{5774 \times 0.8 + 415.8}\right) = 41° 22'$ .... (31)

$PF_s = (Cos\ 41° 22') \times 100 = 75.05$ *percent* .... (32)

$Kv\text{-}a_{sn} = \frac{75.05 \times 6707}{1000} = 503.4$ *kv-a per conductor.* ....(33)

$Kw_{sn} = 503.4 \times 0.7505 = 377.8$ *kw per conductor* ...... (34)

Percent voltage drop $= \frac{6707 - 5774}{5774} \times 100 = 16.16$ ***percent*** .... (46)

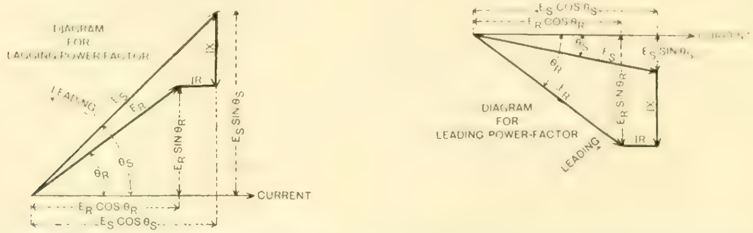
Transmission loss $= \frac{(75.05^2) \times 5.54}{1000} = 31.20$ *kw per conductor* .... (47)

Percent transmission loss $= \frac{31.20 \times 3}{1040} \times 100 = 9.00$ *percent*

MIXED SENDING AND RECEIVING END CONDITIONS FIXED

Branch circuits are frequently run from the main transmission trunk circuit to the center of some local distribution. In such cases the voltage at the sending end and the current or the power and power-factor at the receiving end are approximately fixed. In such cases the calculation for the voltage at the receiving end requires more arithmetical work than is required when all the conditions at one end of the circuit are fixed. Such problems can be more readily solved graphically, as previously explained, but may be solved mathematically by applying formula (44) or (45), Fig. 18.

To illustrate the application of formula (44) we will apply the values of Problem 33 to formula (44) and calculate the receiving end voltage. Thus we have as fixed conditions:—



LOADS OF LAGGING POWER-FACTOR

WHEN RECEIVING-END CONDITIONS ARE FIXED

$$E_S = \sqrt{(E_R \cos\theta_R + IR)^2 + (E_R \sin\theta_R + IX)^2} \quad (30)$$

$$\theta_S = \tan^{-1} \frac{(E_R \sin\theta_R) + IX)}{(E_R \cos\theta_R) + IR)} \quad (31)$$

$$\%\,PF_S = \cos\theta_S \times 100 \quad (32)$$

$$KVA_{SN} = \frac{I \times E_{SN}}{1000} \text{ PER CONDUCTOR} \quad (33)$$

$$KW_{SN} = KVA_{SN} \times \cos\theta_S \text{ PER CONDUCTOR} \quad (34)$$

WHEN SENDING-END CONDITIONS ARE FIXED

$$E_R = \sqrt{(E_S \cos\theta_S - IR)^2 + (E_S \sin\theta_S - IX)^2} \quad (35)$$

$$\theta_R = \tan^{-1} \frac{(E_S \sin\theta_S) - IX)}{(E_S \cos\theta_S) - IR)} \quad (36)$$

$$\%\,PF_R = \cos\theta_R \times 100 \quad (37)$$

$$KVA_{RN} = \frac{I \times E_{RN}}{1000} \text{ PER CONDUCTOR} \quad (38)$$

$$KW_{RN} = KVA_{RN} \times \cos\theta_R \text{ PER CONDUCTOR} \quad (39)$$

LOADS OF LEADING POWER-FACTOR

WHEN RECEIVING-END CONDITIONS ARE FIXED

$$E_S = \sqrt{(E_R \cos\theta_R + IR)^2 + (E_R \sin\theta_R - IX)^2} \quad (40)$$

$$\theta_S = \tan^{-1} \frac{(E_R \sin\theta_R) - IX)}{(E_R \cos\theta_R) + IR)} \quad (41)$$

$$\%\,PF_S = \cos\theta_S \times 100 \quad (32)$$

$$KV\text{-}A_{SN} = \frac{I \times E_{SN}}{1000} \text{ PER CONDUCTOR} \quad (33)$$

$$KW_{SN} = KVA_{SN} \times \cos\theta_S \text{ PER CONDUCTOR} \quad (34)$$

WHEN SENDING-END CONDITIONS ARE FIXED

$$E_R = \sqrt{(E_S \cos\theta_S - IR)^2 + (E_S \sin\theta_S + IX)^2} \quad (42)$$

$$\theta_R = \tan^{-1} \frac{(E_S \sin\theta_S) + IX)}{(E_S \cos\theta_S) - IR)} \quad (43)$$

$$\%\,PF_R = \cos\theta_R \times 100 \quad (37)$$

$$KV\text{-}A_{RN} = \frac{I \times E_{RN}}{1000} \text{ PER CONDUCTOR} \quad (38)$$

$$KW_{RN} = KV\text{-}A_{RN} \times \cos\theta_R \text{ PER CONDUCTOR} \quad (39)$$

GENERAL FORMULAS

WHEN THE VOLTAGE AT SENDING END AND THE AMPERES AND POWER-FACTOR AT RECEIVINGEND ARE FIXED

$$E_R = I(R \cos\theta_R \overset{}{\underset{\bigstar}{\pm}} X \sin\theta_R) + \sqrt{E_S^2 - I^2(R^2 \sin^2\theta_R + X^2 \cos^2\theta_R) \underset{\bigstar}{\pm} 2I^2 R X \cos\theta_R \sin\theta_R} \quad (44)$$

★ USE + WHEN THE POWER-FACTOR OF THE LOAD IS LAGGING AND − WHEN THE POWER-FACTOR IS LEADING

WHEN THE VOLTAGE AT SENDING END AND THE POWER AND POWER-FACTOR AT RECEIVINGEND ARE FIXED

(POWER FACTOR LAGGING)

$$E_{RN} = A\sqrt{1 \pm \sqrt{1 - \frac{(R^2 + X^2)\,KW_{RN}^2 \times 10^6}{A^4 \cos^2\theta_R}}} \quad \text{WHERE } A = E_{SN}\sqrt{\frac{1}{2} - \frac{1000\,KW_{RN}(R\cos\theta_R + X\sin\theta_R)}{E_{SN}^2 \cos\theta_R}} \quad (45)$$

$$\%\text{ VOLTAGE DROP} = \frac{E_S - E_R}{E_R} \times 100 \quad (46)$$

$$\text{TRANSMISSION LOSS} = \frac{I^2R}{1000} \text{ KW PER CONDUCTOR} \quad (47)$$

$$\%\text{ TRANSMISSION LOSS} = \frac{\text{TOTAL } I^2R \text{ (IN KW)}}{\text{TOTAL } KW_R} \times 100 \quad (48)$$

FIG. 18—TRIGONOMETRICAL FORMULAS FOR SHORT TRANSMISSION LINES
Capacitance effect not taken into account.

$E_{sn} = 6707$ *volts*
$I_r = 75.05$ *amperes*
$Cos\ \theta_r = 0.8$
$Sin\ \theta_r = 0.6$
$R = 5.54$ *ohms*
$X = 12.88$ *ohms*
$IR = 415.8$ *volts*

Then

$$E_r = -75.05\ (5.54 \times 0.8 + 12.88 \times 0.6) + \sqrt{6707^2 - 75.05^2\ (5.54^2 \times 0.6^2 + 12.88^2 \times 0.8^2) + 2 \times 75.05^2 \times 5.54 \times 12.88 \times 0.8 \times 0.6} \quad \ldots\ldots (44)$$

$$= -913 + \sqrt{44983849 - 660242 + 385831}$$

$$= -913 + 6637 = 5774 \text{ volts.}$$

To illustrate the application of formula (45) we will apply the values of Problem *33* to formula (45) and calculate the receiving end voltage. Thus we have as fixed conditions:—

TABLE L
ILLUSTRATING VARIATION IN REACTANCE
Resulting from Changes in the Conductors and Transmission Voltages

CONDUCTORS	Total I^2R Loss (KW)	IR		IX		Approximate Voltage Regulation at	
		Volts	Per Cent.	Volts	Per Cent.	100 Per Cent. Power Factor	80 Per Cent Power Factor (Lag)
RECEIVING END VOLTAGE — 6600							
Single Circuit of three 500,000 circ. mil bare overhead conductors	129	123	3.22	622	16 32	4.5	12 8
Two circuits each of three 250,000 circ. mil bare overhead conductors.	129	123	3.22	333	8.73	3.6	7 7
One Circuit of 500,000 circ. mil three-conductor cable. Insulation thickness $\frac{11}{64}$ by $\frac{11}{64}$ inches	129	1.23	3.22	172	4.52	3.2	5.0
RECEIVING END VOLTAGE — 13 200							
Single circuit of three 125,000 circ. mil bare overhead conductors.	129	247	3.22	354	4.64	3 2	5.1

$E_{sn} = 6707$ *volts*
$Kw_{rn} = 346.6$ *kw*
$R = 5.54$ *ohms*
$X = 12.88$ *ohms*
$Cos\ \theta_r = 0.8$
$Sin\ \theta_r = 0.6$

$$A = 6707 \sqrt{0.5 - \frac{1000 \times 346.6\ (5.54 \times 0.8 + 12.88 \times 0.6)}{6707^2 \times 0.8}}$$

then

$$E_{rn} = A \sqrt{1 + \sqrt{1 - \frac{(5.54^2 + 12.88^2)\ 346.6^2 \times 10^6}{A^4 \times 0.8^2}}} \quad \ldots (45)$$

$A = 6707 \sqrt{0.5 - 0.1172} = 4152$

$E_{rn} = 4152 \sqrt{1 + 0.936} = 5774$ *volts*

Alternative to (44) and (45)—The following formulas have been proposed by Mr. H. B. Dwight to meet the mixed conditions referred to,—

$E_{sn} = 6707$ *volts*
$1000 \times Kw_{rn} = 346\,600$ *watts*
$1000 \times$ *reactive* $Kv\text{-}a_{rn} = 346\,600 \times \frac{0.6}{0.8} = 260\,000$ *v-a*
$R = 5.54$ *ohms*
$X = 12.88$ *ohms*
$L = 346\,600 \times 5.54 + 260\,000 \times 12.88 = 5\,270\,000$
$M = 346\,600 \times 12.88 - 260\,000 \times 5.54 = 3\,025\,000$

$$E^2 = 0.5\,E_s^2 - L + 0.5\sqrt{E_s^4 - 4\,E_s^2\,L - 4\,M^2}$$

$E = 5774$ *volts*

or

$$E = E_s - \frac{L}{E_s} - \frac{L^2}{E_s^3} - \frac{M^2}{2E_s^3} - \frac{2L^3}{E_s^5} - \frac{5}{2}\frac{LM^2}{E_s^5} - \frac{5L^4}{E_s^7} - \frac{5L^2M^2}{E_s^7} - \frac{5}{8}\frac{M^4}{E_s^7}\text{*}$$

$E = 5779$ *volts*

CIRCUITS OF EXCESSIVE REACTANCE

If a large amount of power is to be transmitted at comparatively low voltage, particularly if the frequency is high, the reactance of the circuit will be high compared with its resistance. If the reactance is excessive (20 to 30 percent reactance volts may in some cases be considered excessive), the voltage regulation of the circuit may be seriously impaired.

As will be seen by consulting Tables VI and VII, there is a fixed relation between the resistance and the reactance of a circuit for a given frequency, size and spacing of conductors. This ratio is 2.4 times greater for 60 cycle than it is for 25 cycle circuits. For a given size of conductor the reactance can be varied only slightly by changing the spacing of overhead bare conductors. Substituting a larger or smaller conductor may change the resistance materially, but this will have little effect upon the reactance.

The reactance may be reduced by either or all of the following methods. The circuit may be split up into two or more circuits employing smaller conductors and these circuits connected in parallel. The voltage may be raised, if the installation is new, and smaller conductors employed; or the overhead conductors may be replaced by three conductor cables. To illustrate the above methods, the following problem has been assumed and the results tabulated.

A HIGH REACTANCE PROBLEM

Table L refers to the following problem—4000 kv-a, three-phase, 60 cycles, is to be delivered a distance of three miles over hard-drawn, stranded copper conductors. The I^2R loss is to remain at 129 kw. The spacing of the overhead conductors assumed as 3 by 3 by 3 ft. Temperature 25 degrees C.

It is evident from Table L that if two three-phase circuits, each consisting of three 250 000 circ. mil. conductors are installed in place of one three-phase circuit, consisting of three 500 000 circ. mil. conductors, the reactance will be reduced by nearly one half, and a corresponding improvement in the voltage drop or regulation will occur, particularly if the load power-factor is 80 percent lagging. A further improvement along this line will be obtained if a single three-conductor cable is employed. Doubling the voltage for the overhead circuit and employing three 125 000 circ. mil. conductors results in practically as good performance in voltage regulation as for the 6600 volt three-conductor cable.

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*See article by Mr. H. B. Dwight on "Effect of a Tie Line between Two Substations" in the *Electrical Review*, Dec. 21, 1918, p. 966. The formulas given in this article make complete allowance for the effect of capacitance and are very similar to the above.

Inverted Contact Circuit Breakers

H. G. MacDonald

If a current is passed through a conductor which is looped back upon itself, the two sides of the loop will be mutually repelled. If the portion of the conductor included in the loop is free to move, the loop will tend to assume a circular form. The heavier the current the greater will be the force exerted by the conductor in its effort to enclose within its loop the greatest possible number of magnetic lines of force. This phenomenon unfortunately is not confined to a plain conductor under laboratory test but is manifested in electrical structures and under conditions where its effects may be quite disconcerting and even destructive. For example, to open a heavy disconnecting switch requires all the force of a strong man, yet it mysteriously opens of its own volition at the time of a short-circuit on the line in which it is connected. Or a bus-bar is distorted and its heavy supports wrenched loose or broken by the same short-circuit. Or a circuit breaker may have its contacts badly burned or its oil tanks blown off, without its mechanism having opened. These are examples of demonstrations of the enormous forces which develop under the influence of the magnetic field produced by the passage through a conductor of currents of from 60 000 to 100 000 amperes.

Currents of such magnitude are not unknown, during a short-circuit, in many of the large power systems, particularly where no permanent external impedance is placed in either generator, bus or feeder circuits. The practice of connecting reactance in shunt to a circuit breaker so that upon the occurrence of a short-circuit the circuit breaker opens and inserts the impedance in circuit, does not relieve the apparatus of the stresses, as the magnetic forces appear coincident with the first peak of short-circuit current; this occurs before any circuit breaker for this class of service can function. These phenomena are now recognized and the effect of their action provided for; in the disconnecting switch by the addition of a latch which prevents the blade from being forced open, in the bus-bar by the use of rigid, properly braced supports and in the circuit breaker by arranging the current conducting details so as to withstand the forces applied.

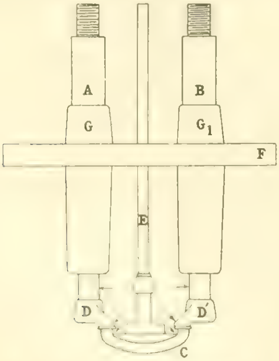

FIG. 1—OIL CIRCUIT BREAKER WITH ORDINARY FORM OF BRUSH CONTACT

Showing the direction of the magnetic stresses on the conductors. Arcing contacts omitted for simplicity.

A common construction of current conducting details used in oil circuit breakers is indicated in Fig. 1, where *A* and *B* represent the leading-in conductors, usually of copper rod; *C* is the moving element in the form of a brush, which bridges the stationary contacts D and D′ on the lower end of rods *A*, *B*; *E* is the lifting rod which carries the moving element C and is carried on the lever mechanism which operates the circuit breaker.

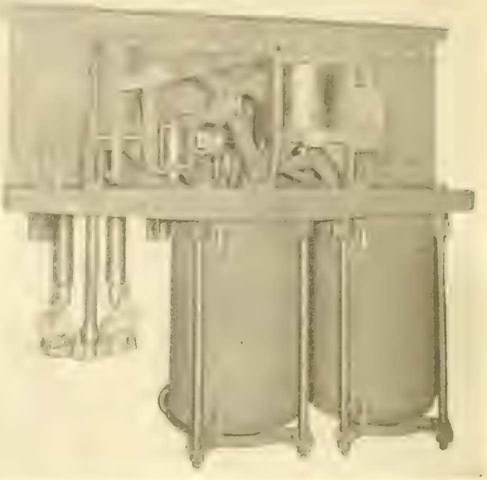

FIG. 2—OIL CIRCUIT BREAKER HAVING BRUSHES REVERSED

To neutralize the effects of the magnetic forces which occur on the passage of a heavy current.

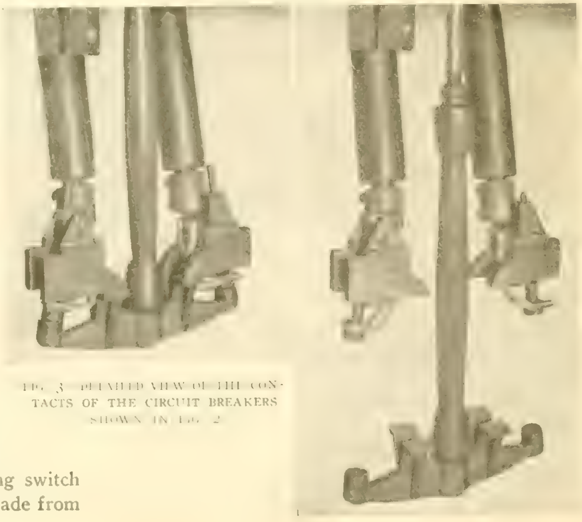

FIG. 3—DETAILED VIEW OF THE CONTACTS OF THE CIRCUIT BREAKERS SHOWN IN FIG. 2

The leading-in conductors *A*, *B*, and the brush *C* form a loop upon which the magnetic forces will act—all in an outward direction as indicated by the arrows. If the rods are long below the supporting frame *F*, as is often the case, the force will tend to push the rods outward, breaking the insulators *G*, G_1 and sliding the stationary contacts away from the brush faces. At the same time the brush itself will be distorted, the forces tending to straighten out the bend—a downward motion of the brush as a whole being prevented by the lifting rod which supports the brush at its middle point. If the supporting details of the leading-in conductors are stronger than the rods *A* and *B*, the rods may be bent.

A form of contact is shown in Fig. 2 in which the forces during heavy current flow tend to increase the pressure between contact elements. The relation of the several parts is reversed as compared with the arrangement in Fig. 1, so that the magnetic force presses the brush more heavily against the corresponding faces on the moving element. The loop between the leading-in conductors or rods and the bridging member still remains, but by supporting the rods where they pass through the frame and by making the length of rod on either side of the point of support nearly equal, the tendency to move out at the lower ends is neutralized, and the leading-in rods are made sufficiently strong to withstand the bending forces imposed. The arcing contacts are also placed in such a position that, when current is shunted through the auxiliary circuit, the magnetic action will not tend to separate these arcing contacts and cause arcing on the main contacts.

One of the limiting features in determining the rating of a circuit breaker is the ability to withstand excessive current rushes at the instant of short-circuit. The effects of the short-circuit current may be mechanical distortion of the circuit breaker structure or a fusing of the current conducting parts due to insufficient thermal capacity. The contact surfaces form a danger point due to the possibility of high contact resistance. The advantages of the modifications in construction just described are quite obvious, as the increase of contact pressure correspondingly reduces the contact resistance and increases the thermal capacity at the formerly weak point.

Farm Line Business at a Profit to the Central Station

H. W. Young, President
Delta-Star Electric Company

IT HAS BEEN ESTIMATED that in the cities there are one million families, worth more than $5000 each. In the country there are six million families, each worth more than $6000, representing a buying market exceeding thirty-six billion dollars. The people living in the country are the majority consumers of the necessities of life and their increasing wealth has made it possible for them to satisfy their desires for the luxuries of life. For example, it is estimated that approximately seventy percent of all automobiles are purchased by them.

The possibilities of this great field for the sale of current and appliances have not been generally recognized by central station executives, who have in many cases absolutely discouraged the so called farm service. The chief reason for this attitude is that central station managers have often labored under the impression that this class of service must be given under the conditions usually found in the cities and small towns. They attempted to finance the entire proposition and assumed all risks when setting the rates for service. Experience has demonstrated that the rates were often set too low and the investment was too high, with a consequent dissatisfaction with this class of service. The writer has made a rather extended investigation of this subject and has come to the conclusion that the average utility manager has overlooked the following facts:—First, that the farmer has a great deal of money to spend; and second, that he wants central station service. Furthermore, the farmer does not regard electric service as a luxury, but as a necessity. His wife wants electric light, an electric washer, an electric fan, an electrically-pumped water supply.

The farmer wants electric motors for operating the cream separator, for grinding feed, for cutting and elevating silage, cutting wood and operating other similar general devices. The farm help want better working conditions, want electric lights which will permit doing chores early in the morning and in the evening, without the necessity of lugging around smelly, inefficient and dangerous lanterns. In fact, everybody on the farm wants town conveniences, knowing that they will help keep everyone contented, will help keep the boys and girls on the farm and make all work easier. Central station electric service will make many of these desires possible and will also largely eliminate the fire risk. They all fear fire, and electric light is not only clean, but inherently safe.

Another point which central station managers usually overlook is the farm labor situation. It is often difficult to get men, yet it takes a man to operate a cream separator and a one-eighth horse-power motor will do the work. If the man is paid 30c an hour, his cost per kw-hr. is approximately $4.

Much work on the farm can be done with electric motors, which consume no current when not in use and have a low depreciation. In fact, if the central station manager gives some thought to the subject of electricity on the farm, he will see that the farmer can well afford to make certain investments to get central station service. This farm power business cannot, however, be secured by the old method which was about as follows: —Farmer "A" came into the office inquiring as to the cost of getting light and power from the central station lines. The utility in all probability looked with disfavor on the entire farm line scheme and gave farmer "A" an array of figures as to the cost of lines, equipment and service which was discouraging, to say the least. The next day farmer "B" came in, the same story was repeated and so on day after day. As a result of these methods both the farmers and utilities lose.

A better way to handle this class of business is by means of the "Service Certificate Plan" which is as follows:—A power solicitor calls on the various prospects and submits to them a service certificate, the acceptance of which and the payment of an agreed amount entitles him to have the power line tapped by means of a transformer, switching and protective equipment. Paying for this service certificate is equivalent to paying entrance dues to a club or similar organization. When a sufficient number of certificates have been paid for to cover the cost of lines, the money can be immediately used to build the lines, which become the property of the power company. High-tension farm power and lighting equipment, transformers, secondary wiring, etc., are purchased by the farmer and installed by a contractor at the farmer's expense, this equipment remaining his property.

The Service Certificate Plan has the advantage of securing concerted action, of insuring a fixed sum for the farmer to pay, enables the utility to give service without too great an outlay and gives the farmer what he wants, central station supply.

For example, assuming that fifty farmers can be reached with a 6600 volt line ten miles long. The line cost will approximate $1000 per mile or a total of $10 000. Each farmer's share of this or the cost of a service certificate will then be $200. A five kw 6600/110/220 volt single-phase transformer, complete with a farm type substation, will cost approximately $300 or a total cost to each farmer of $500 for a five kw installation. This should be compared with a 1000 watt individual plant costing approximately $900 installed, and it is simply a lighting plant with scant power possibilities. The real advantage of central station power service is often better appreciated by the farmer than by the utility managers.

A farmer's substation equipment mounted on a steel pole is shown in Fig. 1. Its general apearance is pleasing, both to the farmer and the utility manager. The equipment consists of a two-pole switch operated by a handle near the ground level, two choke coils, two lightning arresters, and two fuses which can be replaced by the farmer.

Admitting that the method of securing farm line business has been solved, some central station managers will ask the following question:—Will trouble at one farmer's installation, such as transformer burnout, communicate to the main feeder and interrupt service to other consumers? The only thing necessary to prevent the spreading of local short-circuit trouble to other points is to disconnect the defective transformer in such a short time interval that the circuit opening devices on the supply feeder will not have time to open. Thus the opening action of a carbon-tetrachloride fuse under short-circuit conditions is so rapid (approx. 0.013 sec.) that short-circuits at farmer's installations will be cleared approximately ten times faster than automatic oil circuit breakers will open.

Ordinary overloads or short-circuits on the 110/220 volt service lines are taken care of by closely rated fuses of the standard form. With this combination of close secondary and high primary fusing, the carbon-tetrachloride fuses will only blow in case of actual transformer trouble, and such cases are rare.

Each farm power and lighting installation should be inspected at regular intervals as a matter of regular practice, to see that the primary fuses are in proper condition, oil level maintained in the transformer and the arresters in adjustment. This inspection of customer's installation is just as important as the more frequent inspections at the power house and should be part of the transmission company's service.

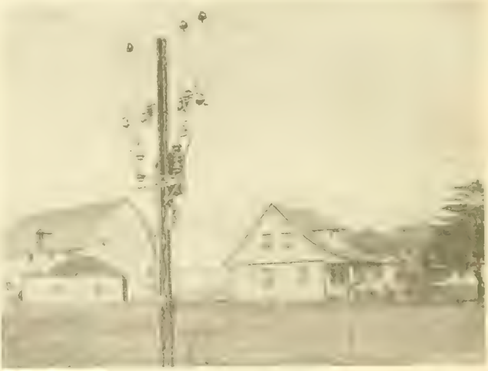

FIG. 1—TYPICAL FARM LINE TRANSFORMER INSTALLATION

When primary fuses are replaced by the farmer, this fact should be reported to the transmission company and inspection made. The transformer trouble causing fuse operation may have been transient and corrected by the sealing action of the coil, but inspection should be made of the oil level condition to guard against further service interruptions.

No utility manager really interested in making a property pay can afford to overlook the farm line business. For instance a town residence bill will approximate $3 per month, and the utility stands the entire investment. The farmers bill will average $6 or more per month, and he stands the investment, reads his meter and promptly pays his bills. Looking at it from this angle, which is the better customer?

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

FEBRUARY 1920

Broken Leads in Armature Windings

Broken leads on armature windings have been a continual source of trouble and expense to some railway companies, while with others such troubles have broken out as an epidemic that ran its course, and then mysteriously disappeared. The most important facts which have become evident in connection with such occurrences are as follows:—

1—Leads are broken only on the coils of direct-current motors which have two or more turns, and on the resistance leads of alternating-current series motors.

2—Breakages usually do not begin to develop until after about one year.

3—Breakages are more frequent where the motors are heavily loaded.

4—The same type of motor will develop breakages on one road and will work satisfactorily on others in apparently the same class of service.

5—This trouble occurs on motors used for city service, as well as in suburban or interurban service.

6—The break commonly occurs on the top leads, directly back of the commutator neck.

7—Top leads have also broken back from the commutator neck, where a sharp upward bend is made in the winding.

8—A few bottom leads have broken, where the top leads are also breaking.

9—On coils where the throw is divided between the top and the bottom leads, no instances are known where the bottom leads broke while the top leads did not. On coils where the bottom leads come out straight to the commutator and all of the throw is on the top leads, the bottom leads have broken more frequently than the top leads.

10—Two piece coils made of thin strap copper have broken at the rear end near where the strap is soldered to the connector.

In an effort to find the cause and remedy for broken leads, considerable experimental and research work has been done, which threw some light on this subject. However, more conclusive results have been obtained by a careful investigation of the troubles reported in the field. Although the cause for each individual breakage could not be located definitely, a number of outstanding points were found in connection with the probable cause, which are listed in Table I.

SUGGESTED PRECAUTIONS FOR PREVENTING BROKEN LEADS

Internal Vibration—

1—The windings should have a solid foundation and should be solidly built up between the top and bottom leads.

2—Small wire leads should be shellaced back of the neck while winding.

3—The complete armature should be dipped in a baking varnish and baked.

4—The laminations of the core should be a tight driving fit on the spider or shaft, and should be held tightly together by a ring nut.

5—The commutator should be clamped under pressure while hot, should be held securely and should make a good press fit on the shaft or spider.

6—The coil supports should be of rigid construction and securely held from movement.

7—All armatures should be temporarily banded while hot, to pull the windings down solidly. The permanent bands should be made of a good grade of hardened steel wire, soldered with pure tin solder. Strips of tin should be placed under the core bands before soldering, to make a more compact band. At the front end, the band should be placed out near the commutator neck to hold the windings securely in place at this point.

8—Excessive currents, such as are produced by too rapid acceleration or through faulty handling of cars should be avoided.

9—Over-speeding, whether on the level or down grades, should be avoided.

10—All detail parts of the armature, as well as the completed armature, should be in balance.

11—Placing a steel wire band on the bottom leads before connecting the top leads has been tried, with but little success.

External Vibration—

1—The armature bearings should be kept tight in the housings and renewed when worn to the allowable limit.

2—The bearing housings should be kept tight in the motor frame.

TABLE I—PROBABLE CAUSE OF BROKEN LEADS

Vibration	Internal	Loose arm winding	Poor workmanship Poor foundation Shrinkage of insulation
		Loose arm core	Worn key Poor fit on shaft or spider Poorly clamped
		Loose commutator	Worn key Poor fit on shaft or spider Poorly clamped Not thoroughly baked
		Poor banding	Not well soldered Poor grade wire Too few bands
		Loose coil support	Worn key Poor fit on shaft or spider
		Excessive current	Overload Rapid acceleration Faulty handling of car
		Out of balance	Core unbalanced Commutator unbalanced Windings unbalanced
		High peripheral speed	
	External	Armature bearings	Loose Worn
		Arm. bearing housings	Loose Worn
		Axle bearings	Loose Worn
		Gear case	Broken Loose bolts
		Axle caps	Broken Loose bolts
		Gears and pinions	Badly worn Out of mesh Eccentric Bottoming
		Track	Special work Poor condition
		Non-resilient roadbed	
		Rigid mounting of motor	
		Faulty handling of cars	
		Flat wheel	
Overloads		Heavy currents	Magnetic stresses
		Overheating	Shrinkage of insulation Loosening of band wire Expansion and contraction of windings
Leads damaged		Leads, nicked	Driving into slot Sharp corners on commutator [illegible]
		Metal changed	Action of heat in soldering Action of the solder
		Metal crystallized by pounding	
Material (Copper)		Mechanically weak, no elasticity	
		Hard copper	
		Impurities in metal	
		Defects in drawing	
Localized Strains		Sharp bends in windings	
		Uneven placing of leads	
		Improper winding	
		Poor distribution of bands	

3—The axle bearings should be kept tight in their seats and removed when worn.

4—The axle cap bolts should be kept drawn up tightly and defective caps should be removed.

5—The gear case bolts should be kept tight, and broken gear cases replaced.

6—Gears and pinions, when badly worn, out of mesh, or bottoming, should be replaced by new ones, preferably of the helical type.

7—Tracks, special work and roadbed should be kept in good condition.

8—Wherever possible, the motors should not be rigidly mounted on the trucks.

9—Flat wheels should be turned or replaced.

10—The trainmen should be given a course of instructions on the proper method of handling the equipment.

Overloads—

1—Excessive currents should be avoided, as they set up magnetic stresses which produce severe mechanical strains in the windings.

2—Heavy currents cause high temperatures that dry out the insulation and cause loose windings and loose bands. Rebanding and dipping and baking the armature every 12 to 15 months helps to counteract trouble from this source.

3—On alternating-current motors with nickel silver resistance leads, provision has been made for movement of the windings, due to expansion and contraction:—

a—By putting a goose neck in the winding.

b—By slotting the winding on both edges of the strap.

4—On direct-current windings where the bottom lead comes out straight to the commutator, a small goose neck bend made in the lead when winding will help to prevent breakages.

Damage to Leads—

1—Utmost care should be used in placing the leads in the slots; metal drifts should not be used.

2—The edges of the commutator neck slot should be rounded off and all sharp corners removed.

3—Leads should not be pounded into the slots.

4—Extreme care should be taken to prevent damage during soldering. Soldering pots should be fitted with a temperature control device to prevent burning the solder or the leads.

5—Some operators have reduced their broken lead troubles by drifting the leads solidly into the commutator necks and not soldering them.

6—One remedy tried, with but little success, was to anneal the leads before soldering them into the necks.

Material—

1—The coils should be made from a soft, grade A, electrolytic copper. The copper to be used should be carefully selected and inspected.

2—As the best copper is mechanically weak, the copper lead can be reinforced by placing a phosphor bronze sleeve over it at the commutator neck.

3—The leads may be cut off at the front end and phosphor bronze connectors used between the cut off leads and the commutator necks.

Localized Strains—

1—The leads should be given a free, easy bend where they enter the commutator neck.

2—No sharp bends should be made in any part of the lead.

3—The leads should be laid evenly and uniformly side by side, to distribute the strain over their entire length, and to reinforce one another.

4—The bands should be wound and distributed in such a way as to reduce the local strains in the leads at the front end.

THE NUMBER OF LEADS BROKEN IN SERVICE CAN BE REDUCED

1—By a good careful winding job.

2—By dipping and baking the armatures.

3—By the liberal use of shellac at the front end of wire leads.

4—By systematic inspection and upkeep of equipment and roadbed.

5—By tight bands. Bands should be renewed approximately every 12 or 15 months.

6—By the use of helical gears and pinions.

7—By not overworking the equipment.

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

To receive prompt attention a self-addressed, stamped envelope should accompany each query. All data necessary for a complete understanding of the problem should be furnished. A personal reply is mailed to each questioner as soon as the necessary information is available; however, as each queston is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply.

1849—Induction Motor Trouble—In a discussion on three-phase induction motor trouble, an engineer asked for the following readings from tests made on the given motor, stating that he would at once point out the trouble, if electrical.

(1) *a*—No load amperes.
***b*—Normal voltage.**
***c*—True watts as indicated by wattmeter.**

(2) (With rotor locked and about one-half normal voltage applied)
***a*—Amperes.**
***b*—Actual volts applied.**
***c*—True watts with a wattmeter.**

(3) Resistance of stator winding —terminal to terminal.

I understand that the magnetization current bears a certain approximate relation to the full-load current, but what should its proportion be to the locked current, at 50 percent normal voltage? Where does he use the stator resistance? When he says "no load amperes" and "watts" does he mean of one line or 1.73 times one line or the total power in other words. How would the primary current with rotor locked compare to the same with rotor removed? With the full-load current.

H.L. (PA.)

If the answers to these questions are known, they can be checked against similar tests made on the motor at the factory or on similar motors elsewhere. Where the values are different, and the design of the motor is known, possible mistakes could be accounted for. When current is specified, it is per terminal and for watts is meant total watts. No-load current, full-load current and locked current do not have any definite relation to each other in different machines. They vary with the number of poles and type of machine.

C.W.K.

1850— Synchronizing —In synchronizing large generators, is there any advantage in closing the oil switch when the synchroscope pointer is nearing the synchronism mark and revolving in a "slow" direction, or is it equally well to close the switch when the pointer occupies the same relative position, but is revolving in the "fast" direction?

R.B.G. (MONT.)

There is no difference, assuming the same phase difference in each case. The current flowing will be determined by the amount of phase difference and whether the generator voltage is ahead or behind the line voltage at the instant the circuit is closed. Whether the generator frequency was faster or slower than the line frequency just before the circuit was closed has no effect on the amount or direction of synchronizing current.

F.D.N.

1851—Starting Synchronous Motor—Please explain how a synchronous motor can be started by tying it to a generator electrically and starting the generator. Also state how large a motor may be started by a 3 000 kv-a., 25 cycle, 6600 volt, turbo-alternator. Could another generator be started as a motor? What does the starting capacity of the set depend on?

C.B. (PA.)

To start a synchronous motor and generator together, the leads should be connected so as to give the desired direction of rotation and the fields of both machines excited. When the generator is started up, the motor will follow and the two machines will come up to full speed in synchronism. It is common practice in making shop tests to connect duplicate machines together, and bring them up to speed in this manner. The 3000 kv-a turbo-generator will probably be able to start a machine of the same capacity without mechanical load. This method can be used with either motors or generators. The starting capacity of such a combination depends largely upon the short-circuit ratios of the machines or, in other words, the ability of the two machines to keep in synchronism. Impedance between the two machines will tend to limit the ability of the generator to start the second machine.

Q. G.

PERSONALS

Mr. F. E. Wynne of the general engineering department of the Westinghouse Electric & Mfg. Co., has been appointed manager of the railway equipment engineering department.

Mr George M. Cullinane, in charge of electrical design and construction in the new billet and structural rolling mill of the Scullin Steel Company, has resigned to take up industrial sales work in the St. Louis district office of the Westinghouse Electric & Mfg. Company.

Mr. Myles Lambert, assistant manager of the railway department of the Westinghouse Electric & Mfg. Co., has been appointed manager of the department, succeeding Mr. W. S. Rugg, who has been appointed assistant to Vice-President.

Mr. Alexander Taylor, manager of works of the Westinghouse Electric & Mfg. Co., has been appointed assistant to vice-president in general charge in all plants of production, stocks and stores. Mr. R. L. Wilson, general superintendent, has been appointed works manager to succeed Mr. Taylor.

Mr. C. W. Johnson, assistant manager of works of the Westinghouse Electric & Mfg. Co., has been appointed assistant director of engineering.

Mr. Ray P. Jackson, of the research engineering department of the Westinghouse Electric & Mfg. Co., has been appointed manager of the material and process engineering department.

Mr. G. A. Sacchi, of the New York district office of the Westinghouse Electric & Mfg. Company has been appointed manager of the stoker section of the power department at the East Pittsburgh Works.

Mr. C. A. Klemm of the Louisville office of the Westinghouse Electric & Mfg. Company has resigned to become assistant manager of the Evansville branch of the Varney Electrical Supply Company.

Mr. J. G. Miles, head of the insulation section of the Westinghouse Electric & Mfg. Company at East Pittsburgh has been transferred to the Seattle District Office as manager of the supply department.

Mr. A. L. Schieber, has been appointed manager of the generator section of the power sales department of the Westinghouse Electric & Mfg. Company at East Pittsburgh to succeed Mr. H. D. Stephens, who has been transfered to the New York district office.

Mr. M. R. Evans, sales manager, and Mr. J. B. Harris, Jr., Pittsburgh district manager of the Pittsburgh Transformer Co., have resigned to act as Philadelphia representatives of the Moloney Electric Company of St. Louis with offices in the Real Estate Trust Bldg. They will also act as Philadelphia representatives of the Delta-Star Electric Company of Chicago.

Mr. E. D. Kilburn, manager of the New York district office of the Westinghouse Electric & Mfg. Company has been appointed vice-president of the Westinghouse Electric International Company at 165 Broadway, New York City. Mr. A. E. Allen, has been appointed to succeed Mr. Kilburn as New York district manager.

Mr. C. W. Davis, manager of the Dallas Office of the Westinghouse Electric & Mfg. Company has resigned to accept the position of vice-president and general manager of the Dallas Light & Power Company.

Mr. Edwin Lundgren, formerly chief engineer of the stoker department of the Westinghouse Machinery Company is now vice-president and chief engineer of the newly incorporated firm, the Frederick Engineering Company of Frederick, Maryland.

Mr. P. M. Lincoln, commercial engineer of the Westinghouse Electric & Mfg. Company and formerly engineer-in-charge of the power engineering department, has resigned to enter the consulting engineer field and in that capacity will have active charge of the motor application engineering for the Lincoln Electric Company of Cleveland, Ohio. Mr. Lincoln will maintain his residence in Pittsburgh until the close of the college year. He has served as professor of electrical engineering in the University of Pittsburgh for a number of years.

TRADE NOTES

The Delta-Star Electric Company of Chicago, have issued bulletin No. 35 detailing plans for serving farmers from high tension lines. It contains considerable data on various forms of contracts for taking on this service at a profit.

"The Toledo Bridge & Crane Company of Toledo, Ohio have just issued two new bulletins. Bulletin No. 21 contains an illustrated list of crane users and applications. The other bulletin describes their type "B" cranes showing details and comparisons with other types of cranes. Both bulletins are elaborately illustrated.

Hickey & Schneider, Inc., of Elizabeth, New Jersey, have just issued their bulletin No. 15 on "Outdoor Disconnecting Switches." This illustrates and describes in detail the various forms of switches available, along with detailed dimensions, sketches, and explanations of the advantages of the designs shown. Copies of this bulletin will be sent on request.

In order to provide facilities adequate to handle the increasing export business and to develop their foreign trade to a greater extent than has been heretofore possible, the Westinghouse Air Brake Company has organized an Export Department with headquarters in the Westinghouse Building, Pittsburgh, Pa. The new department will begin operations January 1st, with Mr. E. A. Craig as Export Manager. Mr. Craig has been associated with the Westinghouse Air Brake Company for thirty-two years, beginning in 1888. In 1905 he was appointed auditor and assistant secretary and in 1906 was made southeastern manager of the Company.

The Gamewell Fire Alarm Telegraph Co.

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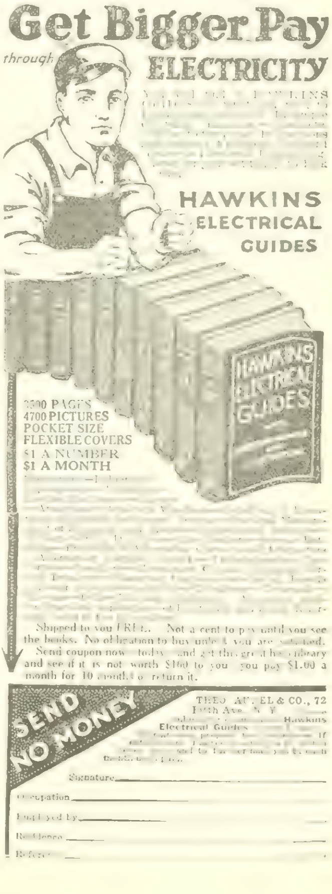

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NATIONAL SAFETY SECTION

In view of the fact that the Electric Journal will run in each issue during the year 1920, a special article on Safety prepared by the National Safety Council and in order that our readers may fully appreciate the value of these articles, we are introducing the series in this issue by a brief history of the National Safety Council.

In a nut shell, the National Safety Council is the nation's clearing house for information on accident prevention, sanitation, and other phases of industrial relations. It is a non-commercial, co-operative association of manufactures, governmental agencies, technical schools, etc. representing industries employing more than 6 000 000 workers.

THE NATIONAL SAFETY COUNCIL

(Continued)

DEVELOPMENT OF LOCAL COUNCILS

In the earliest years of the Council, the need of local activities in organized safety effort in industrial centers began to appear, a need for local organizations which would conduct meetings for workmen, foremen and executives and accomplish what it was impossible to accomplish through printed matter sent from the national headquarters. The National Council therefore set about organizing locals of which there are now thirty-five in operation and at least a dozen in the process of formation. One of the most important steps in the development of local councils was the adoption of the plan of engaging a full-time paid secretary. This was done for the first time by the Pittsburgh Local on Jaunary 1, 1917.

GROWTH OF THE ENGINEERING DEPARTMENT.

In the latter part of 1917 the Council, realizing the need at its headquarters of men with technical experience, created an engineering department which, since then, has had in charge the preparation of all bulletins and safe practices pamphlets. This department now includes four safety engineers who serve the membership of the Council not only in the preparation of bulletins and safe practices but in investigating and answering all inquiries from members for techinical information.

THE [illegible] LIBRARY

From the very inception of the Council, the headquarters office began to develop a library. What began merely as a file of the information that was sent in by members has developed into what is now the most complete library on accident prevention and industrial relations in the country. The N. S. C. library has at least 10 000 booklets and pamphlets, 500 books, 5000 clippings of special articles, and 1 500 blue prints and photographs all devoted to safety or related subjects. The library files contain practically all of the Council's correspondence that is of informative value, tabulated questionaires on a great variety of subjects and a mass of other sources of information. Practically everything that has been issued on the subject of safety by the United States Government and the various state governments is to be found on the shelves of the Council's library and is to be had for the asking by any member.

SCHOOLS FOR FOREMEN AND SAFETY SUPERVISORS.

The most successful feature of the local council work has been the development of schools for safety supervisors, lessons for which were prepared by the Engineering Department. The safety school idea grew out of a need felt by the industries in the Pittsburgh District for trained safety inspectors. It is commonly agreed by experts that a trained safety inspector is indispensable to the efficiency of accident prevention work in any plant. Many companies desire to select safety inspectors from among their own employees. The schools conducted by the various locals of the National Safety Council offer an opportunity for the training of such men. This training is now considered the most direct and effective service that the local councils have rendered.

The schools for safety supervisors have become so popular that the Council has developed plans for organizing schools for foremen. These promise to be equally popular with both employers and foremen and equally effective.

During recent years safety engineers and industrial managers who have given thought and attention to accident prevention have more and more come to see that safety must be incorporated into the community life, not only in order to stop the alarming increase in deaths on the streets and in the homes, but to reach the workmen through their homes, to get them to respect safety and to develop habits of caution.

The Council has not limited its educational work to its own membership. In some forty or fifty universities, through the efforts of the National Safety Council, the faculties have been induced to incorporate safety instruction into the curriculum. These universities are now giving consideration to the requirement of safety both in instruction involving machine designing and in plant management. The Council has set out during the coming year to secure the adoption of instruction in accident prevention in all the public and parochical schools of the country.

The co-operative spirit that has made the National Safety Council possible is perhaps best demonstrated at the Annual Safety Congresses, where some three or four thousand men and women meet to hear formal papers prepared by 150 or more speakers and to participate in round-table discussions on every phase of safety that is of interest to large groups. The Council conducts such a congress in a different industrial center each year. With the congress at St. Louis in 1918, the Council began the practice of conducting with the aid of its local Council, a "safety week" coincidental with the annual congress. These local demonstrations and the resultant heavy reductions in accidents not only added a new spirit and enthusiasm to the Congress, but made a great contribution to the city by arousing interest among the population generally, and especially among industrial workmen.

The National Safety Council starting as an association of a handfull of manufacturers has in six years come to be the one great organization leading the movement not only for accident prevention and industrial betterment, but also the movement for public and educational safety in this country.

WHAT THE NATIONAL SAFETY COUNCIL DOES.

1—Maintains bulletin service. Three posters suitable for posting on bulletin boards, where the messages of care and caution may come directly under the notice of the workmen, are issued each week. One bulletin is issued each week for the executive, bringing to their attention the latest and best plans, methods and ideas for getting the best results from safety work and from other industrial relations activities.

2—Maintains Information Bureau for answering inquiries on all phases of safety work, sanitation, industrial hygiene and other branches of industrial relations. The Council also maintains a complete and comprehensive library on safety which is available to its members.

3—Publishes Safe Practices pamphlets monthly. These engineering studies of industrial hazards are written in plain, every-day English so that they can be understood by every foreman.

4—Lends safety motion picture films and stereoption slides for use at workmen's safety meetings and other occasions.

5— Provides phonographic safety talks, prepared by well-known safety men, for use in lunch rooms and at meetings of foremen, safety committees, workmen and others.

6—Maintains Employment and Registration Bureau for safety engineers.

7—Conducts a Speakers' Bureau and gives training courses for safety supervisors. Also co-operates with technical colleges and universities in presenting safety as part of a course in engineering.

8—Aids in the organization of state and local councils in various parts of the country. At the present time there are thirty-five such state or local councils.

9—Prints weekly news-letter to keep members informed on current events and important matters affecting the safety movement

10—Conducts the Annual Safety Congress in some large industrial center, where papers and discussions on all branches of accident prevention work are given by experts of national and international reputation and where comprehensive exhibits on safety and other questions relating to industrial relations are shown. The Congress at St. Louis in 1918 was attended by over seventeen hundred persons.

THE ELECTRIC JOURNAL

VOL. XVII MARCH, 1920 NO. 3

Graphical Solutions

The importance of quick and accurate methods of calculating overhead transmission lines is rapidly increasing. The electrification of railroads, and the interconnection of large existing power systems are proceeding apace. The increasing cost of transportation, and the shortage of railroad equipment, both tend to make the location of large power stations at the coal mines more and more practicable. At present, prospects look bright for the passage of a Water Power Bill which will permit an increased development of the water powers of the country.

All of these projects involve high-voltage and, in many cases, long distance transmission lines. The low cost of power and the high cost of labor and materials will mean that somewhat larger losses than have been customary, may be considered advisable. This will, in turn, probably produce a widespread use of synchronous condensers for power-factor regulation:—all of which will require not only great refinement in calculation, but also repeated calculations of alternative possibilities.

Mathematical analyses of long transmission lines, are possible; but they are tedious, even to an expert, and are impracticable for the average engineer who, even if he has had mathematical training, usually requires considerable time to familiarize himself again with the processes involved.

Extreme accuracy is not essential in transmission line calculations, as the load and power-factor can only be estimated approximately. The length of a new line, especially over hilly country, cannot be determined exactly. The spacing of wires is seldom uniform; wires are subject to manufacturing variations in size; and their resistance changes with the size, temperature, and purity of the conductor.

With so many sources of variation in the fundamental assumptions, slight inaccuracies in the calculations are negligible. Hence a careful graphical solution is well within the requirements of the problem. Such graphical solutions have long been customary and entirely satisfactory for bridges and roof trusses, where the saving in time is not as great as it is with transmission problems, and where even greater accuracy is essential. The graphical solution minimizes the possibility of making a gross error, and is also very easy to check.

The great majority of transmission calculations are for moderate distances and voltages, for which the effects of capacitance can be neglected, and simple charts, such as those by Mershon and Dwight, (published in the February, 1920 JOURNAL) give the solution almost at a glance. The Dwight chart is especially valuable, because it includes the constants which usually must be secured from wire tables and also because the solutions are reversible. Comparisons of the effects of different wire sizes, etc. can thus be made in a few minutes.

Valuable as these simple charts are, however, for short lines, they neglect certain factors, and for long lines the errors may become important. The graphical solutions by the use of the Wilkinson charts and the diagrams described by Mr. Nesbit in this issue of the JOURNAL are accurate in principle; and the accuracy of the method is attested by the fact that in 48 calculations of high-tension lines performed graphically by Mr. Nesbit, the maximum error, as compared with the most accurate mathematical solutions, was one-quarter of one percent. Such calculations are more accurate than actual measurements of the characteristics of an existing line could be made.

With the Wilkinson charts, the most difficult transmission problems can be solved by a competent draughtsman in a short time, with almost the same accuracy as is obtained laboriously by an expert mathematician by the convergent series or hyperbolic methods. While desirable, an understanding of the mathematical principles involved is not in any way necessary to the attainment of such results.

The correct size of wire for a new line can be determined approximately from Mr. Nesbit's "Quick Estimating Tables" without calculation. Nevertheless it is frequently desirable to compare the performance of a line with several different wire sizes or spacings. Frequently in connection with long transmission lines, both the size of synchronous condenser necessary to maintain certain desired power-factor conditions, and the effect of operating power stations in parallel are involved. Time and labor can be saved by making such comparisons graphically, and even where a complete mathematical solution is considered warranted, a graphical check is of great value.

The broader utility of the graphical solution does not detract in any way from the value of the purely mathematical solutions. A graphical solution should be based on a complete mathematical analysis, since without such a foundation, it can scarcely be considered trustworthy. Great credit is due those engineers who have developed exact formulas for the solution of transmission line problems. Such solutions will always be used for the more precise calculations. No less credit is due those other engineers, such as Wilkinson and Nesbit, Dwight and Mershon, who have translated these formulas into the language of the everyday work shop, so that reliable solutions can be secured quickly and accurately by those who are not mathematical experts.

CHAS. R. RIKER

The New Passenger Locomotives

For the Chicago, Milwaukee & St. Paul Railroad

N. W. Storer
General Railway Engineer,
Westinghouse Electric & Mfg. Co.

THE NEW passenger locomotives for the Chicago, Milwaukee & St. Paul Railroad, which are being covered in a series of articles in the Journal, while apparently a wide departure from all existing types of locomotives, actually contain little of a radically different nature from what has been used before. A great deal of work has been done in developing the various pieces of apparatus, including an immense amount of painstaking detail designing which required the highest engineering skill, as will be seen from the further articles in this series. After all, the result is little more than a new assembly of standard types of apparatus, designed to meet the new conditions imposed by this service, and no new principles are involved. The novelty consists chiefly in the new combinations, different schemes and in the assembly.

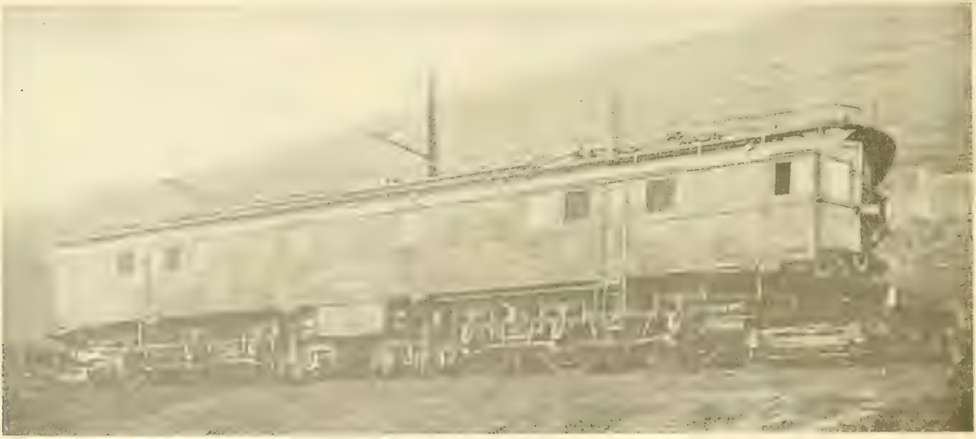

FIG. 1—NEW 4,200 HORSE POWER ELECTRIC LOCOMOTIVE
Used for the Passenger Service on the Chicago, Milwaukee & St Paul Railroad.

The mechanical parts, while designed for a larger locomotive than any that has heretofore been built (it weighs 275 tons), follow the line of development of the latest New York, New Haven & Hartford locomotives in gear drive, single cab and cab supports. The departure comes in the double Pacific-type running gear, with the long coupling bar between halves, and in the minor details of the cab and running gear.

The driving motors, like the New Haven motors, are of the twin armature type, much larger and more powerful it is true, but mounted and geared in the same way. The voltage applied to the individual armature is 750 volts, only a little higher than that of the ordinary street railway motor. The difference lies in the fact that they are insulated for 3000 volts to ground, are of very large capacity, and are operated permanently with four armatures in series. The insulation problem, while serious, offers no insuperable obstacles in the present state of the art.

The arrangement of six motors to secure three running speeds—one-third, two-thirds and full speeds—required a new combination of switches, but the switches used are of the same type and the transitions from one speed to another involve no new principles. It is the old familiar shunt transition that is used.

The unit switch for the high-voltage motor circuits constitutes one of the most important pieces of apparatus, and is one that departs farthest from previous Westinghouse standards; but it is still the electro-pneumatic switch, with extremely ingenious mechanical features and a powerful magnetic blowout. Designed and insulated for high voltage, and connected with several units in series, it handles the 3000 volt current with a facility equal to, or greater than, that of the standard 600 volt switches. For the main motor change-over and the low voltage auxiliary circuits, a very simple design of cam-operated switch is largely used. It is a modified industrial type switch which lends itself very well to this purpose.

The master controller is a model of simplicity, both in construction and operation, considering the work it does, but it differs more from standard designs than most of the other apparatus. The difference is due chiefly to the regenerative braking feature.

The axle-mounted generators used as exciters during regeneration, and to furnish power for auxiliary motors the rest of the time, are, externally, simply low-voltage, separately-excited railway motors. The problem is more serious than that, however, as the generators must commutate satisfactorily over the maximum range of speed, and must operate in parallel.

The auxiliary motors are all designed for 85 to 90 volts, so involve no new principles. The motor-generator has a double commutator, bi-polar motor, wound for 3000 volts. Otherwise it has no unusual features.

Practical considerations of a simple nature have governed in developing this locomotive, as follows:—

1—The high voltage has been confined to that part of the apparatus where it is absolutely necessary. The main motors, unit switches, starting resistors, and the motor of the motor-generator set, with its controlling apparatus, cover the entire list of apparatus on which the high voltage is imposed, except the lightning arrester and resistors for the wattmeter. Even the main motor field windings, and much of the main circuit control apparatus, are connected on the ground side of the armatures, and hence are not exposed to the full line voltage. Control circuits, auxiliary motors, lights, etc., are operated from the 85 to 90 volt circuit.

2—The motor circuit is never opened either in ordinary service or in emergency, without first inserting the maximum starting resistance in the circuit. This practically prevents serious voltage surges and any concentration of vapor from arcs.

3—Regeneration is accomplished by a scheme which has been proven out on several small locomotives*, consisting of:—

a—The stabilizing resistance in the combined separately-excited field and in the armature circuit, which causes the field current to vary inversely with the regenerated current. This protects the motor against sudden changes in line voltage.

b—The axle-driven exciter, which protects the machine against changes in grade, and renders the exciter independent of the line voltage.

c—The method of starting regeneration by connecting the motors to the line with their minimum field current and with the maximum starting resistance in series with them. This limits the initial passage of current to such a small value as to make it impossible to develop an appreciable torque in either direction. After this connection is made, the voltage is automatically and quickly raised to that of the line before the resistance is cut out, when the braking power and speed come under the manual control of the engine-man.

The entire motor capacity of the locomotive is available for regeneration, so that with the ordinary weight of train the load will always be distributed among all the motors, which permits the locomotive easily to hold, on the down grade, a much heavier train than it could haul up grade without a helper.

There are three sources of power for the auxiliary circuits:—the motor-generator set designed primarily for train lighting; the axle-generator designed primarily for exciting the motor fields during regeneration; and the storage battery, which serves as an independent supply, available whether the power is on the line or not. In case the power is off the line, the battery can light the locomotive and operate control circuits and air compressor; or, in case the train is going down grade, it can excite the axle-generators so they can furnish power for the compressors and let the train continue down the grade under the control of the air-brakes.

The capacity of the locomotive is enormous, 4200 hp at the one hour rating, and 3400 hp continuously, corresponding to tractive efforts of 66 000 and 49 000 lbs. respectively. These ratings are based on the standard A. I. E. E. rules. The starting tractive effort is limited only by adhesion, which has exceeded 38 percent on test. If only 33 percent is reached, the tractive effort will still be 112 000 lbs., which requires only 50 percent in excess of the current at the one hour rating. The locomotive has a large margin for the service—so large, in fact, that the blowers are not necessary except on heavy grades. In spite of the enormous pulling power, the locomotive has a safe operating speed of 65 miles per hour and extremely good tracking qualities.

The necessity for lighting and heating the train, and for regenerative braking, has added very largely to the equipment that would be required simply for pulling the train but, as stated before, it does not introduce any radical departures from existing types of apparatus; it simply adds to the amount of apparatus in the locomotive. The success of the locomotive will depend on the perfection of the details and, at this time, the indications are that not only the designers but the builders have done their work remarkably well. The engineers have made a correct analysis of the conditions, and have designed the apparatus to meet them, while the men in the shop have done their part with the greatest fidelity and skill.

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*This has been well covered in the article on "The Axle Generator Regenerating System" by R. E. Ferris, in the JOURNAL for Feb. '20, p. 46.

Electric Dredging on the Yukon

Allen E. Ransom

"There are strange things done, In the Midnight Sun
By the men who moil for Gold" Service

THE WORLD FAMOUS Klondyke, with the city of Dawson at its junction with the Yukon River, has been the scene of so many tales of romance, fortune, and adventure, hair breadth escapes, fabulous fortunes, ice, snow, Indians and the famous Northern lights, that the subsequent arrival of the engineers, their practical study of the situation and its possibilities and how they conquered the many problems, have been to a great extent unheralded even in our engineering world.

The tales of the "Days of '98" were not exaggerated. Along in 1896, Henderson and Carmack, prospecting along the Klondyke River, located on Bonaza Creek, a small tributary of the Klondyke River, a few miles above Dawson. Staking out Discovery Claim and No. 1 below, their Indian guides Tagish Charley and Skookum Jim staked claims No. 1 and No. 2 above the Discovery Claim, and the party proceeded down the river to record their claims at Forty Mile. The strike was a rich one. The whole country headed in for the Klondyke and soon the news spread to the outside and the rush was on. Thousands poured in from all parts of the world. The city of Dawson leaped to a population of 40 000. Chilkoot Pass and White Pass, Fig. 1, were lined with a continuous line of undaunted Argonauts. Lakes Lindeman and La Barge, between the summit and the start down the Yukon, and 150 miles of hard upward climb from Skagway, were passed and the 600 miles of river to the promised land were the scenes of the mad rush. Many fell by the wayside, but the Klondyke was soon staked from mouth to source. Bonanza Basin, Gold Bottom, Hunker Creek, Eldorado, Dominion Creek—all began to give up their treasure under the primitive methods of the early discoverers. Hill and bench claims which were considered by the old experienced miners as useless were forced upon the late comers. However a Swede, one of a party at Forty Mile, was induced to purchase a couple of hill claims for $600 from a couple of miners, who were among the late comers. On the "morning after" he tried to get them to give his money back, but only getting the laugh from everyone, he returned to his claim, continued to dig, reached bed rock and found a fortune. In this way the famous White Channel gravels are said to have been discovered.

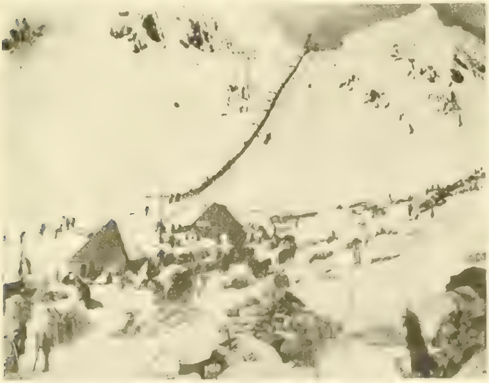

FIG. 1—THE WHITE PASS TRAIL IN '98

Between 1898 and 1905, over one hundred million dollars worth of gold had been recovered by the most primitive means. Engineers, however, had appeared among the many gold seekers, and were quietly studying the situation, figuring out its possibilities and reporting their findings to men with capital in the States. They acquired claims and concessions and made drill tests from hill top to river bottom. Their reports opened up the country to big developments and in 1905 the first of the big operators—the Yukon Gold Company with Mr. O. B. Perry of New York as chief engineer and general manager, commenced operations.

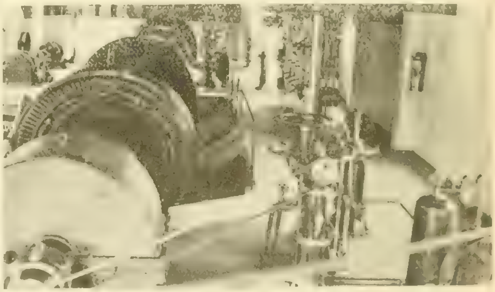

FIG. 2—THE HYDROELECTRIC PLANT AT TWELVE MILE, NEAR DAWSON

At Little Twelve Mile Creek, below Dawson, a hydro-electric plant was constructed, tapping the company's main hydraulic flume, under a head of 650 feet. Three 650 kw, three-phase, 60 cycle, 2200 volt, Westinghouse revolving field alternators direct connected to Pelton wheels, with their necessary complement of exciters, switchboards and step up transformers, Fig. 2, were installed and the power transmitted at 33 000 volts over a 36 mile transmission line with 18 miles of branch lines to nine electric dredges in the Klondyke basin.

The possibilities of the dredging operations had been carefully studied and, as in the case of the other companies following later, thorough reports had been approved, based on analysis of the following conditions:—

1—Quantity of gold bearing gravels in the properties acquired.
2—Distribution and value of gold contents.
3—Depth and character of gold to be worked.
4—Cost of labor, transportation and supplies.
5—Length of operating season each year.

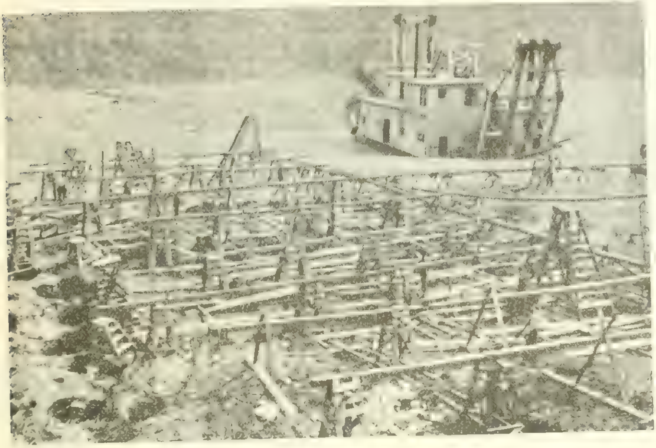

FIG. 3—A GRAVEL THAWING INSTALLATION
Operating on Bonanza Creek, ahead of dredge "Yukon No. 5."

6—Cost of power operation and maintenance.
7—Quantity, nature and cost of removal of overburden soil.
8—Proportions of gravel to be treated by hydraulicking hill claims, ground sluicing bench claims and dredging river bottom claims.
9—Cost of thawing glacial frozen gravel.
10—Cost of thawing plant, operation, fuel and maintenance.
11—Clear titles.
12—Continuous claim dredging permits to prevent holding back of dredging operations.
13—Keystone placer drill hole tests on all claims, ahead of the dredges, hydraulic or sluicing flumes.

All of the above having been worked out satisfactorily, the ground was prepared for the dredges. Fig. 3 shows a thawing installation ahead of the dredges. A net work of pipes supplied with steam at about 100 pounds pressure is constructed with downward pipes at frequent intervals. At these points, lengths of pipe, tipped with needle-like points and slotted to permit the steam to escape, were driven into the frozen ground and, as the escaping steam thawed the gravel, they were pushed on in until bed rock was reached. This was carried on over an extended area and the plant then taken up and moved on ahead, while the dredge following close behind, worked the thawed out ground. Careful records, covering a number of years, placed the average thawing costs of frozen gravel at 13 cents per cubic yard. These costs apply to operating conditions during the years from 1906 to 1914.

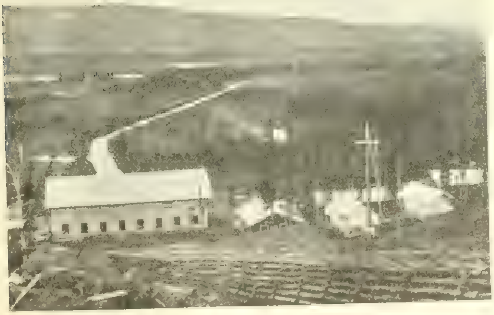

FIG. 4—NORTH FORK POWER HOUSE OF THE CANADIAN KLONDYKE MINING COMPANY

At about the same time, the Canadian Klondyke Mining Company with Mr. Joseph Boyle as general manager, constructed a 10 000 horse-power hydroelectric plant near the North Fork of the Klondyke River about thirty miles above Dawson, Figs. 4 and 5. A ditch about five miles long, which carries the water to the penstocks is equipped with electric heaters at the intake and at one mile intervals, to thaw out the anchor ice which was held suspended in the flowing water at the beginning and end of each dredging season. The electrical equipment consists of two 3000 kv-a, three-phase, 60 cycle, 2200 volt, 514 r.p.m. revolving field alternators, direct connected to 5000 horse-power reaction turbines, which operate under a 450 foot head. There are two 85 kw, 125 volt exciters, one driven by a motor and the other by a 30 inch water wheel; and a six-panel switchboard. Two banks of transformers, each consisting of three 1250 kv-a, oil-insulated, water-cooled units, step the voltage up from 2300 to 33 000 volts.

At Bear Creek, an auxiliary steam turbine station, consisting of a 500 kw steam turbogenerator plant at 2200 volts, three-phase, 60 cycles was installed to furnish light and power to the main repair shops and works, as well as to the City of Dawson during the winter months. This plant also served as a means of limbering up the different dredges each spring before the water power plant was opened up, which was

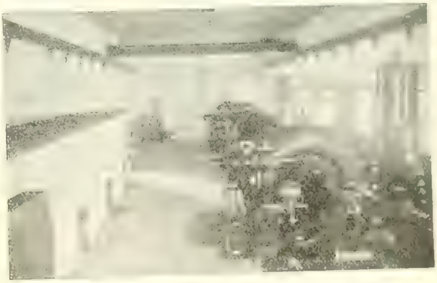

FIG. 5—INTERIOR OF NORTH FORK POWER HOUSE

generally in the month of April or May. An exceptional run of weather at times enables the water plant to operate late in the year. Fig. 6 shows one of their large steel dredges operating at Christmas time in 1913, at 30 degrees below zero.

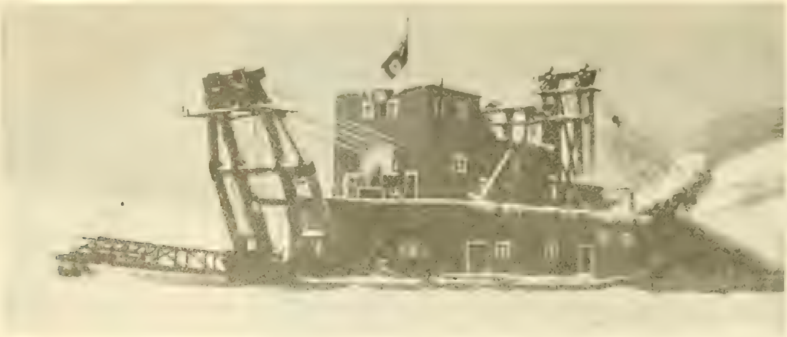

FIG. 6—ELECTRIC DREDGE IN OPERATION ON CHRISTMAS DAY, 1913

The Canadian Klondyke Mining Company placed in operation four electric dredges, three of which were of the 17 cu. ft. per bucket type and had twice the capacity of the Yukon Gold Company's machines. For a number of years the power plant of the Canadian Klondyke Mining Company, being at a lower level than the Twelve Mile plant, could start earlier and run later in the season, and having a larger capacity, carried the entire load of the Yukon Gold Company, the city of Dawson and its own dredges, the systems of all the companies being interconnected at Bear Creek Junction. A third company which came into the field, only completed its power station and transmission lines, and was forced by legal and other complications to shut down. However, this gives an idea of the large projects entered into and risked in the mining game. Locating a coal deposit at Coal Creek, about 60 miles below Dawson, a 10 000 horse-power steam turbine station with a 13 mile railroad, boilers, condensers, coal mining machinery and all modern accessories were shipped from England, across Mexico, up the coast to Skagway and part way around by St. Michaels. It was placed in operation and connected by a 40 mile 33 000 volt transmission line with the Dawson systems. After an investment of nearly $3 000 000 it was operated only 100 days, due to legal difficulties and the lack of coal at the supposed mine at Coal Creek. This plant is shown in Fig. 7. Later it was taken down piece by piece and shipped to Japan and today delivers its kilowatts to the paper mill industry of that enterprising country.

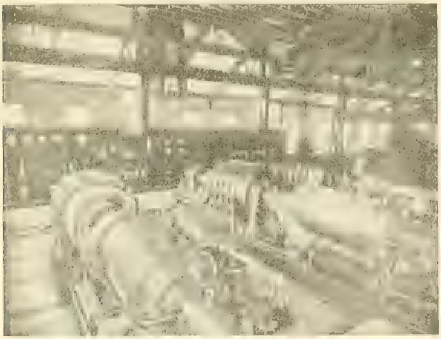

FIG. 7—10 000 HP STEAM TURBINE PLANT, COAL CREEK, ALASKA

The type of electric dredges used in the Yukon district are of the close-connected bucket-type, and similar to those used by the operators in the Conrey Placer Diggings at Ruby and Virginia City of Montana and the Marysville district of California. The Yukon Gold Company dredge "Yukon No. 5," and the Canadian Klondyke Mining Company dredge, "Canadian No. 3," shown in Figs. 3 and 8 are typical examples of modern electric dredge construction. Their general description is given in Table I:—

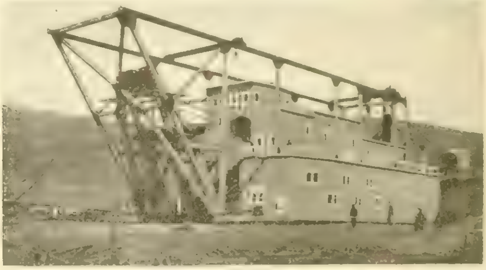

FIG. 8—DREDGE CANADIAN NO. 3 IN OPERATION

TABLE I—DREDGE DATA

	YUKON No. 5	CANADIAN No. 3
Maker	Bucyrus Shovel Co.	Marion Shovel Co.
Hull	Wood	Steel
Capacity	5000 cu. yds. per day	12000-16000 cu. yds.
Type	Close connected bucket	Close connected bucket
Power	400 volts, three-phase, 60-Cycles	2200 volts, three-phase, 60-cycle
Hp. of motors	Total, 305	Total, 1120
Length of hull	98 feet	136 feet
Width of water line	[illegible] feet	56 feet 6 inches
Depth	8 feet 6 inches	14 ft bow 12 ft 6 in stern
Draught	6 feet [illegible] inches	8 feet 6 inches
Capacity of bucket	7.5 cubic feet	17 cubic feet

Weight of bucket	1750 pounds	4600 pounds
No. in line	70	68
Digging ladder	80 feet long	97 feet long
Upper tumbler	12 000 pounds weight	38 000 pounds weight
Lower tumbler	8000 pounds	28 000 pounds
Revolving screen	6 feet inside diameter	9 ft. 6 in. inside diameter
Revolving screen	20 000 pounds weight	126 000 pounds weight
Stack ladder	89 feet long	115 feet long
Conveyor belt	32 inches wide	48 in. wide, 238 in long
Steel spud	24 by 36 inches	38 by 54 in by 65 ft. long
Steel spud	30 000 pounds weight	62 000 pounds weight

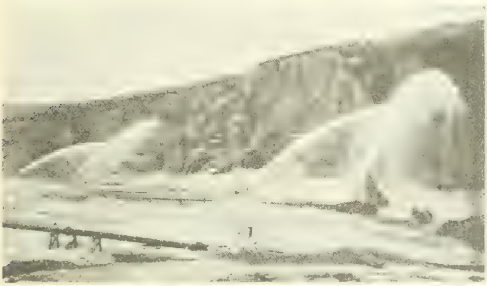

FIG. 9—HYDRAULIC GIANTS IN OPERATION

On the property of The Yukon Gold Company, Lovett Gulch.

MOTOR EQUIPMENT

YUKON No. 5 400 volts, three-phase, 60-cycles

100 hp	Main drive	Variable speed	580 r. p. m.
90 hp	Sluice pump	Constant speed	850 r. p. m.
15 hp	Prime pump	Constant speed	850 r. p. m.
20 hp	Winch	Variable speed	850 r. p. m.
50 hp	Screen	Constant speed	514 r. p. m.
30 hp	Stacker	Constant speed	850 r. p. m.

Total, 6 motors, 305 hp.

CANADIAN No. 3 2200 volts, three-phase, 60-cycles

300 hp	Main drive	Variable speed	345 r. p. m.
200 hp	Ladder hoist	Variable speed	600 r. p. m.
150 hp	Screen drive	Variable speed	600 r. p. m.
150 hp	16 inch pump	Constant speed	600 r. p. m.
150 hp	14 inch pump	Constant speed	600 r. p. m.
35 hp	4 inch pump	Constant speed	600 r. p. m.
50 hp	Winch	Variable speed	600 r. p. m.
50 hp	Stacker drive	Constant speed	600 r. p. m.
35 hp	Stacker hoist	Variable speed	600 r. p. m.

Total, 9 motors, 1120 hp.

TABLE II—OPERATING DATA FROM MAY TO NOVEMBER 1914

	YUKON No. 5	CANADIAN No. 3
Running time	3189 hours	5745 hours
Power consumed	461 590 kw-hr.	2 457 200 kw-hr.
Ground worked	801 667 cubic yards	2 341 910 cubic yards
Total operating expense*	$34 227	$86 376
Cost per cubic yard*	4.28 cents	3.67 cents

FIG. 10—GROUND SLUICING, LOWER DOMINION

Some interesting figures of the average cost for dredging were worked out in detail from actual operating figures for the nine dredges of the Yukon Gold Company, as given in Table III.

In order to obtain the values from the adjoining bench and hill claims, the Yukon Gold Company operated hydraulicking plants extensively through 10 and

TABLE III—OPERATING DATA, 1914

	Cents per cubic yard	
Indirect Costs		
Fixed salaries	0.07	
Labor	2.51	
Fuel	0.05	
Shop repairs	0.43	
Material and supplies	1.86	
Power	1.28	
		6.20 cents
Direct Costs		
Preliminary	1.66	
Bullion charges	1.67	
General charges	2.44	
Depreciation	[illegible]	
Insurance	0.13	
Assay office	[illegible]	
Stables	[illegible]	
Company telephone	0.03	
Miscellaneous	0.05	
Development	0.50	
Dredge development	0.71	
		[illegible] cents
Thawing		12.18 cents
Total cost per yard		27.62 cents

Length of season, 148 days.
Time operated, 82.8 per cent.

Average yield per cubic yard	54.21 cents
Average cost per cubic yard	27.62 cents

15 inch water lines, with No. 1 giants under 80 lbs. pressure as shown in Fig. 9, and ground sluicing from flumes as shown in Fig. 10, the debris being directed through riffle bottom sluice boxes from which the gold was later collected.

FIG. 11—OAT FIELD ON HUNKER CREEK

The actual operating cost for electrical dredging during 1912 was 9.6 cents per cu. yd. However by 1914 the cost had been reduced to 7.6 cents, showing a decrease of two cents per cubic yard.

Though actual figures to date are not available in all their details, it can be safely said that over 400 million dollars worth of gold have been taken from these Arctic fields and the difficulties and problems involved have been overcome by scientific and practical study. Alaska today, with its vast unexplored territory and its wealth of gold, copper and other minerals, is still to be exploited. Its resources are unlimited, and for the engineer it is a country of many promises. The photographs of the Hunker Creek oat-field Fig. 11, and the Bear Creek potato field Fig. 12 show actual summer crops in the center of the dredging district. The Alaska grayling and salmon are always to be had in the streams and large herds of caribou and moose and many bears are frequently seen within a few miles of the larger rivers.

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*Not including ground thawing

The railroad transportation over the coast range through the wonderful scenic White Pass, Fig. 13, and the Yukon boats plying down the Yukon from White Horse, have made this country one of the coming fields of the world for development. The vast reaches tributary to the Yukon—the Pelly River district, the Atlin and Whitehorse gold fields, the upper and lower Porcupine, the far away MacKenzie Land, on down to the Tanana, the Iditarod, Fairbanks, Cordova and the Copper River, Valdez, Prince William Sound, St. Michaels and the famous beaches at Nome are all available to the prospector and engineer.

FIG. 12—POTATO FIELD AT BEAR CREEK, NEAR DAWSON

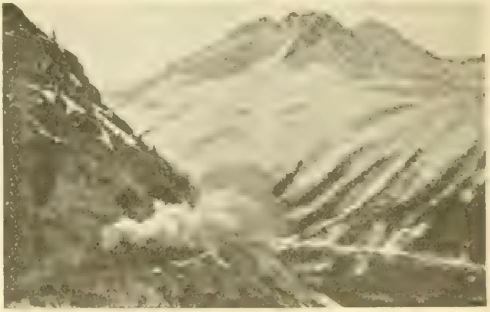

FIG. 13—THE WHITE PASS SCENIC RAILROAD

Mystery and doubt are being swept away by the practical engineers of today.*

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*The writer is indebted to the Minister of the Interior of the Dominion of Canada for written permission to use data and cuts in this article from his official publication. "The Yukon Territory, Its History and Resources."

Lubrication of Steam Turbine Bearings

H. V. Schoepflin

For the proper lubrication of the various bearings of a steam turbine unit, it is vitally necessary that a continuous supply of clean pure oil be maintained at a few pounds pressure, at the same time providing efficient means for carrying off the heat generated in the bearings. It has been found that one of the most satisfactory methods of cooling the bearings is to cool the oil itself before the bearings are supplied, the heat generated being thus transferred to the oil, which is then returned to the system and recooled before it again reaches the bearings. In order to prolong the life of the oil, the reservoir which contains the supply must be of ample capacity so that the oil may have as long a period of rest as is possible between the times of actual use in a bearing. By providing a strainer in the discharge line from the bearings, to remove any foreign matter from the oil before it is returned to the reservoir, a constant supply of clean lubricant is assured, although occasional filtering is necessary to remove impurities which pass through the strainer. In some of the more elaborate oiling systems a partial filtration system has been added, providing for a continuous purification of a small percentage of the oil actually in use, which small amount is being constantly drawn out from the bottom of the reservoir and returned to the system after it passes through the filter.

The oil circulation is maintained by means of a pump, which is positively driven from the governor spindle by spur gearing, the governor itself being worm driven by the turbine shaft. In order that the oil supply may be maintained when starting or stopping the turbine, the pump is supplemented by an auxiliary pump, which is usually steam driven. The procedure when starting up the unit is first to start up the auxiliary pump, the turbine spindle not being turned over until the bearings are flooded with oil; then, when the turbine reaches full speed and the main pump has attained full capacity, the auxiliary is shut down, and the main pump supplies the system as long as the turbine is running. This procedure is, of course, reversed when shutting down the unit.

A common arrangement of cooling system in general use on steam turbine units of modern design is shown in Fig. 1. The oil is pumped from the reservoir through the cooler, which is composed of a nest of tubes, to the bearings. The cooling water is forced through these tubes at high velocity and the oil circulates outside the tubes, rapid and efficient cooling being thus assured. After being discharged from the bearings the oil, now at a slightly increased temperature, is carried by gravity through the strainer to the reservoir, from where it is again pumped through the complete cycle repeatedly.

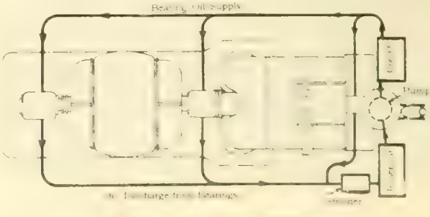


FIG. 1—OIL COOLING SYSTEM

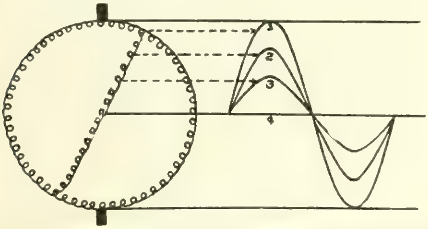
Where the governor valves of the turbine are operated by an oil relay system, it is necessary to provide oil at a fairly high pressure for use in the operating mechanism, and the pump must consequently be designed for the higher pressure. In such cases the oil is first pumped into a surge tank, where the proper pressure for supplying the valve operating mechanism is maintained by means of a spring loaded relief valve. The discharged oil, together with that escaping from the surge tank through the relief valve, passes through the cooler and thence to the bearings. Otherwise, the oiling system is identical with that first described.

The Technical Story of the Synchronous Converter—Cont.

B. G. Lamme
Chief Engineer,
Westinghouse Electric & Mfg. Co.

THE THREE-WIRE CONVERTER

In 1897, while studying some of the conditions occurring in synchronous converters, the writer, discovered certain curious characteristics. If one lead of a circuit were connected to one of the direct-current brush arms of a converter, while the other lead was connected to one of the collector rings, a pulsating unidirectional e.m.f. could be obtained, varying from zero to a maximum. This is illustrated in curve *1*, Fig. 2. The writer in his study assumed the case where one terminal, instead of being connected to the collector ring, or transformer terminal, would be connected to the secondary of the transformer some distance in from the terminal. It developed that this would also give a pulsating unidirectional e.m.f., as in the former case, but with lower peak value. This is indicated in curve *2*, Fig. 2. Of course, the next step was to move still further in on the transformer, giving conditions as in curve *3*. From this, it was inferred that if the terminal were moved to the middle of the step-down transformer coil, then the resulting e.m.f. would be constant in value and of half the value of the direct-current e.m.f. of the converter itself. In other words, this tap at the middle of the transformer secondary would give an intermediate voltage between the two direct-current brushes; that is, it constituted a three-wire machine. On the heels of this discovery, a proposition came up where a customer wanted a three-wire system supplied by 60 cycle converters. The writer proposed the use of a standard two- phase, 60 cycle, converter, but gave no explanation of the method by which it was intended to obtain the mid-voltage. This method of suplying three-wire systems was used quite extensively in the following years.



PULSATING UNDIRECTIONAL E. M. F. BETWEEN A BRUSH ARM AND A TRANSFORMER TAP

THE INVERTED CONVERTER

As early as 1895, a converter operating invented in connection with other apparatus on test suddenly speeded up, and before anything could be done, the armature windings burst. This was blamed on the carelessness of the tester, in accidentally weakening or opening the field circuit. However, some months after this, a converter of fairly large capacity was installed in the company's power plant, tying the alternating-current and direct-current power systems together. After this machine was installed, the switchboard operator noted that the alternating-current load on the plant had fallen to a point where the converter could carry it all and therefore he decided to cut out the alternating-current generators and carry all his alternating-current load through the converter. It so happened that this load consisted of magnetizing current for induction motors which were running empty. The moment the operator transferred this load to the converter, the latter speeded up so quickly that it burst the armature windings before the operator could reach any disconnecting switches. The writer was called in and as soon as he heard the facts, the explanation was simple enough and he stated that, of course, the converter would run away, for the wattless current in the armature would have a demagnetizing effect, just as in an alternating-current generator, and therefore the converter had "killed" its own field. He was then asked what remedy could be applied to avoid future trouble. He said, offhand, that as the converter ran away, the remedy should be one depending upon change in speed. He suggested that the converter be separately excited from a small generator driven in such a way that the exciting generator would speed up directly with the converter, and thus furnish increased excitation with increase in speed. A set of this description was soon "rigged up" and afterwards operated in connection with this converter with entire success and the trouble was never repeated in this plant. The exciters for inverted converters were usually direct coupled; that is, placed directly on a shaft extension of the converter itself. This use of a separate exciter was later adopted by other companies and is used today where inverted operation, with highly inductive loads, is one of the requirements.

VOLTAGE REGULATION OF CONVERTERS

After synchronous converters had become accepted practice, it was found necessary to develop some means for varying the voltage of the direct-current for railway work, and for other kinds of service, such as three-wire systems. It was recognized that the most effective method of regulating the direct-current voltage in synchronous converters was by varying the alternating-current voltage supplied. This led to the application of "step-by-step" voltage regulators, and later to the use of "induction type" regulators. About 1894, Mr. C. F. Scott proposed that the alternating current voltage up plied be boosted proportionally to the load, by means of a small alternating-current generator on the shaft of the converter, the field of which would be excited by the direct-current from the converter itself. In this way, a true compounding action could be obtained. This scheme contained the essential elements of a later development which eventually eliminated the induction regulator, as far as converters were concerned.

Previous to 1906, the British Westinghouse Company had built converters with small alternating-current generators (or synchronous boosters, as they are now called) connected to the alternating-current side, such boosters being separately, instead of series excited. They thus differed from the above scheme only in the method of excitation. In 1906 the American Westinghouse company built a 500 kw converter, along the same lines, for the Carnegie Steel Co. This type was also suggested to the engineers of the New York Edison Company as an alternative to the induction regulator scheme. Its possibilities so appealed to them that they placed an order for a comparatively large machine. Records indicate that this was the first synchronous booster converter put into service in this country.

About 1907, the General Electric Co. brought out the so-called "split-pole" converter, in which the ratio of the alternating to the direct-current voltages of the converter itself was varied by changing the field flux distribution. The split-pole arrangement required no auxiliary machine, but on the other hand, it was inherently larger than the booster type, and it was not well adapted for certain conditions of operations. There were points in favor of each type of machine, but with the coming of the commutating-pole construction, the synchronous booster type presented very material advantages, as the regulating-pole type of converter became unduly complicated with the addition of commutating poles, or their equivalent.

The synchronous booster had the alternating-current regulating generator connected between the collector rings and the armature winding of the converter. Thus the booster was necessarily of the rotating armature type, with a stationary field, just like the converter itself. Apparently compactness, general simplicity and neatness of appearance had much to do with the adoption of this arrangement as a general standard.

However, it must not be overlooked that other methods for varying the direct-current e.m.f. of converters had been proposed and used quite extensively. The principal one of these had been used for a great many years in compounding converters for railway service. From the very first, it was recognized that the power-factor of the alternating-current input to the converter could be controlled by varying the excitation of the synchronous converter field. It was also known, that the power-factor of the current in a transmission system had a direct influence on the voltage regulation at the end of the transmission line. With these two facts put together, the conclusion was reached that if a converter was given increased excitation, with increase in load, for the purpose of changing the power-factor, the effect of the improved power-factor would be to give a more uniform or even a rising voltage at the point where the load is taken off. Therefore, with this in view, the writer suggested, very early in the work, that converters should be compounded for the purpose of maintaining more uniform voltage. Independently, Mr. R. D. Mershon went a step further and proposed the use of additional reactance in the transmission line, in order that the change in power-factor could produce a still greater range in voltage. Eventually, this arrangement narrowed down to the use of reactance on the alternating-current side of the converter for compounding purposes.

FURTHER 60 CYCLE DEVELOPMENTS

The introduction of the turbo-generator represented considerable improvement in the operation of converters. However, the most serious limitation was in the small pole pitch and the small distance between neutral points, as explained before. There had been considerable development in armature and commutator construction, and finally the writer urged a radical step in the 60 cycle converter development in the way of materially increasing the peripheral speeds of both the armature and the commutator. According to his analysis, a 25 percent increase in the pole pitch would work wonders, for all this increase, with a given interpolar space for good commutation, would appear as increased pole width. For instance, with an interpolar space six inches wide for good commutation, and the pole itself six inches wide, making a pole pitch of twelve inches, a 25 percent increase in pole pitch would mean that the pole could be increased to nine inches in width or would be 50 percent wider than before. This would represent a very big improvement in the magnetic conditions, reducing the maximum voltage per bar very greatly. Also a 25 percent increase in commutator peripheral speed would allow a corresponding increase in the number of commutator bars per pole, thus further reducing the volts per bar. These radical steps were taken and this development probably represented the greatest single advance in the 60 cycle synchronous converter design. However, it took one more important step to bring the two frequencies more nearly together.

COMMUTATING POLES IN CONVERTERS

This next step consisted in the introduction of commutating poles. This construction had been developing for a number of years in direct-current generators and motors and in railway motors, but up to the period of 1910 to 1912, converters had been practically exempt. There was a good reason for this, however. In the direct-current machine, commutation was a more serious limitation than in the converter, for the large, low-speed converters of that time, in general, had extremely good commutating characteristics. However, the real field for commutating poles was found when synchronous converter speeds were so increased that commutation became a true limitation.

Both 25 and 60 cycle converters shared in this increase in speeds. The larger 25 cycle machines had their speeds doubled in a number of cases, by halving the number of poles. In the smaller 25 cycle machines, this could not be done because the number of poles was already as small as could be made, practically. Consequently, the smaller 25 cycle converters did not share to any extent, in the decreased size and cost and in the improved performance of the larger machines.

In the 60 cycle development, however, all the machines, from the smallest to the largest, had a relatively large number of poles and thus there could be a material decrease in the number of poles with correspondingly increased speeds, improved performance and decreased size and cost. The improvement in performance of the 60 cycle machines was considerably greater than on the 25 cycle. In the former 25 cycle converter, the iron loss was a relatively small proportion of the total losses, usually being less than the armature copper loss. Increase in speed represented a decrease in both iron and copper loss. In the 60 cycle machines, however, the iron loss in the older machines was relatively high, being sometimes from five to ten times as great as the armature copper loss. Doubling the speed, for instance, reduced this iron loss practically one-half. In consequence, the 60 cycle machine was improved in efficiency to a greater extent than the 25 cycle, and was brought so close to that of the lower frequency machine that it became seriously competitive, especially when transformer efficiencies were also included. The decrease in cost of the 60 cycle machines was also apparently greater than in the 25 cycle machine, and this also brought them closer together. In fact, the gain in cost and performance in the small 60 cycle machines was enough to make them more than competitive with the corresponding 25 cycle machines, so that they have practically succeeded in driving the small 25 cycle converters out of the market. Thus, due to improvements in generating or supply conditions, certain radical changes in design, and the addition of commutating poles, the 60 cycle converter has changed, from what was considered a questionable machine, to a most serious competitor of the 25 cycle line. With the development of complete cage types of dampers, very much like those in the secondaries of cage-type induction motors, both 25 and 60 cycle damping conditions were improved, but the 60 cycle were improved much more than the 25 cycle. This was therefore another step in advance.

STARTING OF SYNCHRONOUS CONVERTERS

There is another part of the synchronous converter story, which has hardly been touched upon. One method of starting, namely, that used on the Chicago World's Fair exhibition machines, has already been referred to. This consisted in the application of relatively low voltage to the collector rings, and bringing the machine up to synchronous speed, after which it was transferred to full supply voltage. This method was practically the same as present day practice, except that the starting device was more complex, having several steps, whereas at present, rarely more than two steps are used, a starting and full running position. This early method was not considered practicable, the "pull" on the supply system was thought to be excessive. Voltage regulation in those days was entirely by hand and small generating plants were in use. At present with larger plants in use, a converter, even of the largest commercial size, represents only a small percentage of the power plant capacity.

To overcome the difficulties in starting the converter on alternating-current, several methods were devised and used quite extensively. In 1895, the Westinghouse company began using induction motors for starting converters. The first time that this method was put into service was on a 500 kw converter of the Niagara Falls Power Co. A six-pole induction motor was direct connected to the shaft of the converter for bringing it up to speed. It was thought that the problem of starting from rest and speeding up was the serious one, and that, as synchronous speed was approached, the current "pull" would not be serious. However, actual operation indicated that the starting motor should be able to pull the converter up to true synchronism. In consequence, on later designs, starting motors were installed which could accomplish this result. This was done by making the starting motor with two less poles than the converter itself, so that the synchronous speed of the starting motor was higher than that of the converter.

Various methods were adopted for bringing the converter to exact synchronous speed and holding it there long enough to allow connection to the line without disturbance. In some cases, the no-load losses in the converter, when excited to normal voltage were sufficient to give load enough on the induction motor to hold the converter at approximately its synchronous speed. However, it was an unusual case when this came exactly right. The starting motor had to meet two conditions, namely, it had to have enough torque at standstill to overcome the friction-of-rest of the converter. Second, it had to develop just enough torque at the synchronous speed of the converter to hold a reasonably constant speed. Frequently, it was impossible to get a speed-torque curve of the induction motor, which would meet these conditions, without the aid of auxiliary appliances. For instance, with a six-pole converter and a four-pole starting motor, the motor had to run 33 1/3 percent slip, for synchronizing the converter. Even with a straight line speed-torque curve, this meant that the starting torque could be only three times the synchronizing torque, and in many cases, this was not sufficient to overcome the friction at start. By supplying higher voltage to the starting motor, a higher starting torque could be obtained, but the torque at two-thirds speed would be increased correspondingly, and consequently, the converter would reach stable speed at some point considerably above that required for synchronizing. One remedy for this in some cases was to greatly overexcite the converter, increasing its no-load losses and thus increasing the slip of the starting motor. This, however, meant synchronizing with the line at considerable over-voltage. A second way was to connect a small resistance load across the direct-current end of the converter, thus pulling down its speed the required amount. Another way was to connect a transformer, with a cast-iron core, across the alternating-current side of the converter. All of these methods had to do with starting motors with cage secondary windings. In some cases, starting motors with wound rotors and regulating resistances were used, but this scheme in general, was not used.

Synchronizing difficulty generally occurred only with converters having six poles. With eight-pole converters and six-pole starting motors, the conditions were much more satisfactory. In general, the higher the number of poles the easier it was to get good synchronizing conditions. However, this method of starting did not apply at all to four-pole converters, for this meant two-pole starting motors and the conditions for synchronizing would have been very difficult. In the later years of the starting motor method, commutator-type single-phase series motors were used in some cases, with means for adjusting their speed. These could be used with four-pole converters, and therefore were of especial advantage with the smaller 25 cycle converters.

The disadvantage of the motor method of starting was that the converters had to be synchronized. One advantage was that the polarity of the converters always came right. However, the objections to synchronizing were considered as serious and eventually the method was abandoned, except in special cases.

A second method of starting consisted in bringing the converter up to speed by means of direct-current. However, in railway work, the direct-current voltage supply often was so variable that it was difficult to hold the converters anywhere near constant speed. To over come this difficulty, in some cases the converter was brought slightly above synchronism by direct current, disconnected from the direct-current system and then switched over to the alternating-current system as it dropped through synchronism.

A third method consisted in the use of special sources of direct-current supply, such as motor-generators or storage batteries. The source of supply, being of practically constant voltage, there was no difficulty in holding reasonably constant speed at synchronism. This scheme required synchronizing devices just like the starting motor scheme, and moreover, the synchronous converters came up with the right polarity. Where there were a number of converters in one station the cost of the motor-generator set, or other means for getting a constant voltage supply, was often-times no greater than that of starting motors on each converter.

In starting synchronous converters on direct-current, there was one condition which was sometimes encountered, which was a source of more or less trouble. In some instances, the step-down transformers were connected permanently to the collector rings of the converter without switches, all switching being done on the high-tension side of the transformers. In such cases, the low-tension, or secondary windings of the transformers were liable to form more or less complete short-circuits across the direct-current brushes of the converter, depending upon how the collector rings were connected to the winding. In two-phase machines, with taps at 180 degree points on the winding, it is obvious that with these taps in line with the brushes, the direct-current supplied for starting could go, to a great extent, through the transformer, instead of the converter windings. In such cases, the converter was liable not to start. With six-phase converters with diametral connections, the same conditions held. In consequence, with such connections, it was sometimes necessary to help start the converter by mechanical means. Of course, when once in motion, the current into the transformer immediately decreased. In six-phase machines with direct-current starting, double-delta connection to the transformers was generally used to prevent severe short-circuiting of this nature. In three-phase machines, dead short-circuits by the transformers were not possible, for there were no taps across a diameter, and always part of the armature winding had to be in circuit. Double-delta connection with six-phase is, of course, the equivalent of three phase, with respect to short-circuiting.

However, even with three-phase converters, the short-circuiting effect of the transformers with this arrangement was very considerable. For instance, with the 1500 kw converters for the Manhattan Elevated, motor-generators of 50 kw capacity were provided for starting the converters. On test, these starting sets were ample for starting the converters, but here the lowering transformers were not connected to the converters. When installed in their substations, however, it was found that these 50 kw units were very heavily overloaded at times in starting the converters, due to the short-circuiting action of the transformers. Tests were made to determine what influence the position of the collector taps had on the starting torque and current, and it was found that, as far as the synchronous converter was concerned, its torque varied over a wide range depending upon the position of the taps, and in all cases, it was considerably lower than when no transformers were connected.

However, years ago, the present method of direct starting by alternating-current supplied to the collector rings was used, first on a small scale and afterwards on large machines, because it represented, a cheaper and somewhat more convenient method than any of the others. At first, this method of starting, was considered as more or less of a hardship, as far as the supply system was concerned, but with the development of voltage regulator for the supply generators, this method made greater headway.

As the power systems grew in capacity and in size of units, they presented easier and easier conditions as far as converter starting was concerned, and therefore, this method came into greater use until it practically superseded all others. This method has the advantage that synchronizing apparatus is not needed and, while the wrong direct-current polarity may be obtained, yet by slipping a pole this can be corrected very easily.

In some cases in recent years, a combination of the motor starting method and the direct alternating-current method has been used. In this special method, the supply current is fed through the primary winding of a starting motor and then to the synchronous converter armature. The starting motor is thus in series with the synchronous converter and, at start and during acceleration, a relatively small current flows in the converter armature, but this current is large enough to produce a quite heavy torque in the starting motor. The small current in the armature of the converter is insufficient to reverse the polarity of the synchronous converter field, so that as the machine comes up to speed, it excites itself with its normal polarity, and when synchronism is reached all that is necessary is to short-circuit the induction motor.

COMMUTATION

The problem of commutation was never very serious in the synchronous converter except in some of the later synchronous booster types where special conditions are found.

One reason why the commutation on the synchronous converter has been a simpler problem than on the direct-current generator is that the magnetomotive force of the armature is relatively small, being the resultant of the alternating and direct-currents in the armature, whose magnetomotive forces are in opposition. Thus at 100 percent power-factor, the resultant m.m.f. averages only about 15 percent of that which the same winding would give as a direct-current generator. In consequence, the magnetic field, due to the armature, in which the commutating coils are short-circuited, is smaller than in a direct-current machine, and converters without commutating poles can commutate from 30 to 50 percent more current than the corresponding direct-current machines.

When it comes to flashing, converters have often proved to be more sensitive than direct-current machines. There have been several reasons for this. In the first place, being tied to an alternating-current system, the converter, on a direct-current short-circuit, not only could act as a direct-current machine, but could take current from the alternating-current supply system, thus giving a very high peak current. In the second place, on a sudden application of heavy load, or on a short-circuit, part of the current, at least, is due to the machine acting as a direct-current generator and, in consequence, the armature m.m.f. is increased enormously over that as a converter. Moreover, under this condition, tests have shown that the converter may tend to hunt badly for a moment. This hunting simply means that the m.m.f. of the armature is rising to a relatively high value, first in one direction and then in the opposite direction, with accompanying field distortion. This explains a rather curious condition, which was noted years ago; namely, that converters frequently flash worse after the direct-current circuit breaker is opened on a short-circuit, than they do at the moment of application of the load. The sudden load produces the conditions for momentary hunting, but very often this hunting does not really begin until the circuit breaker opens. In consequence, any flashing due to the hunting action occurs after the direct-current circuit breaker has opened and the apparent cause of the flashing has been removed.

This action is quite clear from some tests made to determine the effect of opening the direct-current circuit breaker when a converter was carrying heavy overload. The conditions in the tests were such that hunting could readily be determined. It was found that hunting began the moment a very heavy load was opened by the circuit breaker and, on a well-damped converter it lasted for three or four "beats" approximately. In some cases, the hunting action was so violent that there was great tendency to flash at the brushes during this period. Obviously, under such conditions, anything that would lessen the hunting tendency would reduce the tendency to flash. Proof of this was furnished in a curious way in the case of commutating-pole converters, as will be explained later.

With commutating-pole converters, the problem of commutation was easier than on direct-current commutating-pole machines, except where the speeds were very greatly increased, accompanying the addition of commutating poles. Doubling the speed made the commutating conditions much more difficult than before and a condition was reached where commutating poles were a real necessity, in order to obtain good commutation, as the commutating constants were about twice as high as in the former non-commutating machine.

A curious situation arose in connection with the early application of commutating poles to synchronous converters. It was known that, in direct-current commutating-pole machines, it is bad practice to surround the commutating-pole with any closed low resistance electric circuit, as this acts as a damping circuit to make the commutating-pole flux sluggish, so that it cannot follow quick changes in the load. It was thought that similar conditions would hold in the synchronous converter. In consequence, it was assumed that the copper dampers on the main poles of the synchronous converters should not enclose the commutating-poles. However, later actual operating conditions indicated just the contrary. In one case where a number of large synchronous converters were to carry 300 percent short-time loads, there was bad flashing when the circuit breakers came out. The service engineer then put a short-circuited winding on the commutating-poles, as an experiment, and found that the flashing was reduced. Tests were then made with full cage dampers on the poles of certain converters, these dampers necessarily completely enclosing the commutating-poles. These machines flashed to a less extent than any of the others, thus showing that a closed circuit around the commutating-pole was an advantage. According to calculations, the complete cage damper had about twice the damping effect of other types of dampers and, in consequence, the hunting, with sudden removal of load, was much diminished. The reduction in the hunting tendency apparently more than counterbalanced any bad effect of the low resistance circuits around the commutating-poles.

This effect of the complete cage damper in preventing flashing is apparently much more pronounced in commutating-pole machine than in the old non-commutating-pole type for the following reasons:—In the commutating-pole converter, the magnetomotive force on the commutating-pole winding is comparatively small, as it must overcome only the small resultant armature reaction, averaging about 15 percent of the direct-current plus about 20 percent commutating field. This winding thus is made about 35 percent as strong as the m.m.f. of the armature itself, considered as a direct-current machine. The corresponding commutating-pole m.m.f. of a direct-current machine could be about 125 percent. Thus the commutating-pole m.m.f. of the average converter is only about one-third that of a corresponding direct-current generator. Here is a source of possible trouble; for, if for any reason, such as hunting, the resultant armature m.m.f. rises to a value comparable to that of a direct-current machine, it very greatly overpowers the commutating-pole winding, and in consequence, magnetizes in the opposite direction through a good magnetic circuit. The commutating-pole flux thus may not only be reversed, but may rise in the wrong direction to a value which will give most vicious sparking, thus tending to produce flashing. Thus, when a commutating-pole converter hunts badly, with the resultant m.m.f. rising to high peak values, there is a tendency to flash during such hunting. In consequence, anything which will reduce hunting will lessen this flashing condition. Therefore, the complete cage damper, as described before, with its ability to reduce the hunting tendency, has been quite effective in reducing flashing.

When it came to building booster converters capable of giving a fairly wide range in voltage, a new difficulty was encountered, particularly in commutating-pole machines. An analysis of the armature conditions showed that, under different loads with different "boosts" and "bucks", the resultant armature m.m.f. is not proportional to the current output of the machine. In consequence, it is not practicable to excite the commutating-poles in series with the leads from the commutator, as in the ordinary converter. Neither will a shunt winding or direct combination of series and shunt meet the required conditions. In consequence, it has been necessary to develop special regulating methods for exciting the commutating-pole windings for the synchronous booster type of machine. This has been a difficult problem, but eventually practical schemes were developed which enabled the commutating-poles to be excited to a suitable value at all times.

COMMUTATORS, BRUSH-HOLDERS AND BRUSHES

From the standpoint of the commutator itself, the greatest development in recent years has been toward rigid constructions with higher peripheral speeds. With decrease in the number of poles and increase in the revolutions per minute for a given output, the number of brush arms has decreased, the diameters of the commutators have decreased materially and the lengths have increased. A smaller diameter, with a higher peripheral speed and a greater length, means a more difficult mechanical construction, and this has been one of the serious problems in synchronous converter construction, the currents per brush arm have increased from 400 to 500 up to 1500 amperes. This development has been accompanied by a certain amount of service trouble, as short-time shop tests cannot possibly bring out all the difficulties nor show how to overcome them permanently. However, enormous progress has been made in this matter and, presumably, the commutator situation is as good at present as it has been in the past.

As to direct-current brushholders, these have also gone through considerable development. In the early days, the problem was simpler than at present. In the first place, with lower currents per brush arm, there were fewer brushes per arm and less difficulty in obtaining average distribution of current among the brushes. In the second place, brushes of somewhat lower resistance have come into use and these have made the problem of distribution of current more difficult. In the third place, with the coming of commutating-poles there has been the necessity, in large converters, for the development of brush lifting devices in connection with bringing the converters up to speed by the direct application of alternating-current. In the old non-commutating-pole converters, the coils short-circuited by brushes were located in a relatively large interpolar space, with no iron directly over them.

In starting and accelerating, the converter armature is simply the primary element of an induction motor, the field structure being the secondary. A rotating or traveling flux is set up, but in the vicinity of the coils short-circuited by the commutator brushes, this flux is of quite low value in non-commutating-pole machines due to there being no iron over the coils. In consequence, the short-circuiting effect of the brushes was not seriously harmful. In the commutating-pole machine, however, especially in large sizes, the commutating-pole itself, during starting, furnishes a good magnetic path directly over the short-circuited coils, and in consequence, a quite heavy flux is established at these points. This develops large e.m.f's. in the short-circuited coils, with consequent heavy sparking during acceleration. For this reason, it has been found desirable to install brush-lifting devices to take care of starting. When it is considered what a large, complex structure the brushholder system forms, it may be appreciated that this brush-lifting device adds very considerable complication which has been one of the difficult problems in modern design.

COLLECTOR RINGS AND BRUSHES

Taking up next the question of collector rings, it would appear, offhand, as if the collector rings represent a comparatively easy problem. But in fact, it has become one of the truly difficult problems in converter design, especially in recent years. The quantity of current to be handled is one of the sources of trouble, especially in the modern high-speed machines. When one considers that the total current to be handled by all the collector rings is practically three times the current delivered by the direct-current end (or neglecting efficiency, $2 \times \sqrt{2} \times$ d-c.) one can appreciate that the problem is largely one of quantity of current. However, the commutator handles the direct-current twice, so that the total current handled by all the collector rings is approximately one and one-half times the total handled by the commutator. It is this heavy current which has been at the bottom of nearly all collector ring difficulties in converters.

Early in the development, converters were made either two-phase or three-phase. As all the rings are connected to one common winding, two-phase is really four-phase and, therefore, the early converters were either three-phase or four-phase. In the earliest calculations of the losses in synchronous converters, as already described, the three-phase machine showed 57 percent of the copper losses of a direct-current armature winding, whereas the four-phase showed 38 percent. Obviously, the losses decreased with increase in the number of phases, or collector rings. Mr. R. D. Mershon worked this out at a very early date, and his calculations showed that with six-phase the losses were about 26 percent and that, with enormous further increase in the number of collector rings, the losses would be decreased to 12 percent. The general conclusion was that six rings represented a considerable gain over four rings, but that it would not be worth while to go further. Mr. Mershon, the writer believes, was the first one to propose the use of six collector rings for converter work. However, this suggestion was not adopted until later, as there was apparently no particular advantage, in the early machines, in going beyond three or four rings.

In considering the collector rings themselves, the earliest types were entirely enclosed on the sides by the intervening insulating barriers, and therefore, with no ventilation except at the wearing surface. Copper leaf brushes were used, with relatively small contact drop, and therefore for moderate current capacities the losses were not high. However, with more difficult conditions, it was found that there was undue heating of the rings and the open type of collector was developed in which the rings themselves were carried on open arms or spokes, so that the air could circulate freely. This increased the carrying capacity of the rings enormously. Several leaf brushes were used on each ring, as it was found that the ordinary brush could carry only about 200 to 250 amperes and very often the current per ring was several times this.

A curious thing developed early in this work in regard to collector ring "wear." It was discovered that in some cases the rings would get "out of round" in a peculiar way. In a six-pole machine, there would be three high spots and three low spots on the ring, equidistantly spaced; in an eight pole machine, four highs and four lows, etc. The difficulty was not due to actual mechanical wear of the collector rings, but to burning under the brushes. It was recognized in a general way, years ago, that a current passing from a brush to a commutator or ring in motion would tend to burn or "eat" away the brush surface, but not burn the ring to any extent; while in passing from the ring, or commutator, to the brush, the former would burn but not the latter. In the commutator both actions take place, due to both polarities being on the same commutator, and, therefore, the effect is usually not noticeable. However, in converter collectors the current passes alternately in each direction in the rings, but assuming a single brush on the ring the current would be from the ring to the brush in one part of the ring, representing one pole arc, and would be in the opposite direction in the part representing the next pole arc. Consequently, within a given segment or part, the current is always in a given direction with respect to the brush and the ring. In consequence, in one segment the ring would tend to burn away, while in the next segment it would not. Consequently, if there were any burning of the rings, they would tend to get out of round, with as many low spots as there are pairs of poles.

In some of the early converters, in laying out the brush spacing, accidentally the brushes were so spaced, with respect to the rings and the poles, that this burning action was accentuated, while in other machines, the spacing of the brushes was such as to give fairly uniform burning tendency over all the ring. In consequence, in some machines the rings would run out of true, while in others they would not. As soon as this became of sufficient importance to attract attention, the difficulty was overcome by remodeling the brush supports and respacing the brushes. It was also noted that this action was particularly bad with very high current densities, and in such cases, the brush capacity was increased materially to lessen this effect.

The copper leaf brushes, being very flexible, could follow quite easily any slight variations out of true. Moreover, with low contact drop and the good ventilation of the open construction, the rings ran at relatively low temperature. Consequently, undue expansion did not come in as a factor, as has proved to be the case in some of the later work. However, one serious objection to the copper brush was that its wear resulted in a deposit of fine copper dust and considerable attention was required to keep the parts clean. However, this method of operation lasted until the "metal graphite" brush came into use.

Many years ago, certain brush manufacturers in Europe produced graphite brushes with fine metal particles in them, which appeared to have very good carrying qualities, with low contact resistance; this latter being about one-fifth that of an ordinary carbon brush. With such brushes available, the manufacturers of synchronous converters undertook to use them on collector rings to overcome the objectionable features of the copper leaf brushes. These brushes were tried on quite a number of machines of different types. It was found that the current densities, claimed practicable for these brushes, were much too high for American practice and, therefore, much larger brush capacities had to be adopted. Special brushholders had to be devised to meet the brush characteristics and a number of new difficulties were encountered which had not appeared with copper brushes. One of these was the effects of irregularities in the collector rings themselves. With copper brushes, as stated before, the rings could run out of true slightly, without having any appreciable effect. It was soon found, however, that with the metal graphite brushes, the rings could not be out of true, to anything like the same degree, as the brushes could not "follow" the surface properly and maintain sufficiently intimate contact. In other words, there was a "heel-and-toe" contact when the rings were out of round, with momentary local high current densities between the brush and the rings, with corresponding tendency to burn.

Also, with the higher contact brush resistance, there are considerably greater losses in the rings and brushes than with copper brushes and, in consequence, greater heating of the rings results, accompanied by greater expansion. As the rings, especially in the larger machines, must be of spider construction for ventilation purposes, it has been a serious problem to design rings which would not warp out of round with increase in temperature. A considerable amount of difficult engineering has been carried on to overcome the various troubles and to maintain, at the same time, good ventilation. In recent years of synchronous converter work, there has been, possibly, no more difficult problem than this one of collector rings with graphitic brushes.

In small synchronous converters, there has been possibly more trouble, in proportion, than in any of the larger sizes. This is partly due to the fact that there is insufficient room for dampers of good size, without making the machine unduly large. Such machines also appeared to be very sensitive to prime mover and transmission drop conditions. Some years ago the writer made a small 1.5 kw converter of the induction type, as already described. The principal purpose was to make a machine which would not hunt under bad supply conditions. This little machine was later tried out on a generator plant where the generators would not successfully parallel with each other, and yet it operated without any hunting whatever. Of course, being of the induction type, its power-factor was comparable with an induction motor of about the same capacity. This was a most interesting little machine, and the writer has always believed that something further could have been accomplished with this principle.

In high voltage railway work, which has developed in recent years, there has been a call for converters of 1200 to 1500 volts and many outfits of this nature have been built. For 60 cycles, it has always been the practice to couple two machines in series, as it appears to be physically impossible to make a good 1500 volt, or even 1200 volt, 60 cycle converter with one commutator.

In 25 cycle converters, it has been practicable to build single machines up to 1500 volts with first-class operating characteristics. However, apparently there has been no attempt, up to the present, to operate two of these in series, commercially, to give 3000 volts.

Two-phase, three-phase and six-phase converters have been considered. Obviously, at some time in the development, single-phase converters necessarily came up for consideration. Very early in the development, the analysis of the losses showed that, when operating single-phase, a synchronous converter would have considerably greater armature copper losses than on direct current alone. Consequently, this method of transformation was not considered as economical. However, from time to time, cases came up where single-phase operation was necessary, under emergency condition and, in one case, a converter was operated for several weeks on single-phase supply with apparently no harmful effects. However, in a large synchronous converter, it was noted, in transforming from direct-current to single-phase, that there was considerable vibration of the dampers which eventually became so loose that their supports had to be changed to more substantial ones. It was recognized that this was due largely to the backward rotating component of the alternating-current m.m.f., magnetizing effects of which were largely neutralized by the dampers in the poles. This introduced a double-frequency current in the dampers themselves, which set up vibration. Apparently, however, with properly constructed dampers, a well proportioned single-phase converter would operate just about as well as polyphase, except for higher losses and other inherent conditions.

GROWTH OF CONVERTER BUSINESS

As already explained, at the time of the Manhattan Elevated and the New York Subway work, the 1500 kw, 25 cycle units were in demand and it was felt that, while larger units might be used occasionally, the field was not large enough to call for much larger capacities. However, a few years later, 2000 kw units were bought on a comparatively small scale, and then a few 3000 kw were built. It then developed in a short time that a still larger unit was advisable and the 4000 kw, 25 cycle machine was brought out, which size has proved very desirable for heavy work. Apparently this 4000 kw size seems to meet all the needs at present.

In 60 cycle units, some seven or eight years ago, there was a sudden increase to 1500 kw as a standard unit, although before this, machines as large as 2000 kw, of the slow-speed type had been installed. With the coming of higher speeds, commutating poles, etc., and improved constructions, the 1500 kw, 60 cycle converter has proved to be a good one for railway work, while units of 2500 kw, and even larger, have been used very extensively for lighting purposes, electrochemical work, etc.

As to the future, no one can say where the upper limit will be in the capacities of synchronous converters. In 60 cycle machines, there is still opportunity for relatively higher speeds, as the number of poles for a given output is still much less than in corresponding 25 cycle machines. In the latter, apparently the upper limit in speed, or very close to it, has been reached.

The present high stage of development of the synchronous converter is necessarily the result of the cooperation, as well as the competition, of many able minds. The writer wishes it to be understood that his engineering associates, as well as the engineers of other manufacturing companies, should share in the credit for this great development. From the personal references in the body of the paper, it might be inferred that he did practically everything himself; on the contrary, except in the early stages, in many instances he acted only in an advisory capacity in the various developments, thus keeping in close touch with the problems at hand.

Switchboard Meter Connections for Alternating Current Circuits-III

Three-Phase, Three-Wire Circuits

J. C. Group

In a three-phase, three-wire circuit, such as shown in Fig. 28, the three voltages are 120 degrees apart. Usually the circuit is arranged so that the phase rotation is *1 2*, *2 3*, *3 1*, that is, the voltage in phase *2* is a maximum in the direction from line *2* to line *3*, 120 degrees after the voltage in phase *1* is a maximum in the direction from line *1* to line *2*. Also the voltage in phase *3* is a maximum in the direction from line *3* to line *1*, 120 degrees after the voltage in phase *2* is a maximum in the direction from line *2* to line *3*. In the following discussions, it will be assumed that the circuits are arranged for phase rotation as explained above.

Load circuits fed by a three-phase three-wire system may consist of delta or star connected three-phase circuits or single-phase circuits. Single-phase circuits may be connected to any one or all of the three phases. Regardless of what kind of a load is taken from such a system, the current which flows out on any one line must return on one or both of the other lines, and for that reason two current transformers are sufficient for making complete measurements with meters.

The arrangement for a delta-connected, three-phase load circuit is indicated in Fig. 29, and a vector diagram for this circuit for a balanced load at unity power-factor is shown in Fig. 30. The vectors $E_{1\,2}$, $E_{2\,3}$, and $E_{3\,1}$ represent the three line voltages 120 degrees apart. Since the phases of the load circuit are connected between lines, the respective phase currents are in phase with the line voltages at unity power-factor and are represented by $I_{1\,2}$, $I_{2\,3}$ and $I_{3\,1}$ on the vector diagram. Each line current consists of a combination of two currents differing in phase, and is, therefore, different in amount and phase position from the phase currents. In Fig. 29, the positive directions of the various currents assumed for the circuit, are indicated by the small arrows. It is evident that the line current, I_1, is equal to the difference between $I_{1\,2}$ and $I_{3\,1}$, since the currents I_1 and $I_{3\,1}$ are flowing toward the point A and $I_{1\,2}$ is flowing away from it. In this case, the vector difference must be used instead of the algebraic difference, because the currents are not in phase. On the vector diagram in Fig. 30, $I_{1\,2} - I_{3\,1} = I_1$ (vectorially) and I_1, being 30 degrees behind $I_{1\,2}$, is $\sqrt{3}$ times the phase current. The line currents I_2 and I_3 are derived in a similar manner. From the vector diagram, it may be seen that the three line currents I_1, I_2 and I_3 are 30 degrees behind the line voltages $E_{1\,2}$, $E_{2\,3}$ and $E_{3\,1}$ respectively.

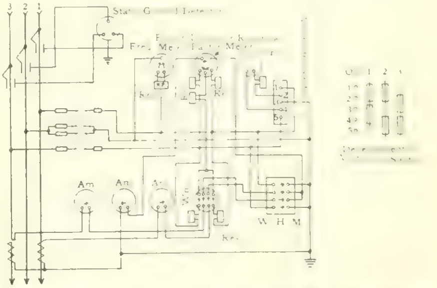


FIG. 28—METER CONNECTIONS WITH SEPARATE AMMETERS AND VOLTMETER SWITCH

The power consumed in a balanced, delta-connected, three-phase load at unity power-factor is $3EI_p$, where E is the three-phase line voltage and I_p the phase current. But $I_p = 1/3\sqrt{3}\,I$, where I is the line current and, therefore, the power is $\sqrt{3}\,EI$ in terms of the line voltage and line current.

The arrangement for a star-connected, three-phase load is indicated in Fig. 31. One end of each phase of the load circuit is connected to a line and the other ends of the phases are connected together in a neutral point *o*. The phase currents are the line currents and are in phase with the phase voltages or the voltages from the lines to neutral. Each line voltage is a combination of two phase voltages and is different in amount and phase position from the phase voltages. In the vector diagram for this arrangement, shown in Fig. 32, the phase voltages are represented by the vectors $E_{1\,0}$, $E_{2\,0}$ and $E_{3\,0}$, 120 degrees apart, and the currents in phase with these voltages by I_1, I_2 and I_3 respectively. The line voltage, $E_{1\,2}$, in the direction from line *1* to line *2* is equal to $E_{1\,0} - E_{2\,0}$ (vectorially) and being 30 degrees ahead of $E_{1\,0}$ is $\sqrt{3}$ times the phase voltages. The other line voltages $E_{2\,3}$ and $E_{3\,1}$ are derived in a similar manner. The three line currents I_1, I_2 and I_3 are 30 degrees behind the line voltages $E_{1\,2}$, $E_{2\,3}$ and $E_{3\,1}$ respectively.

The power consumed in a balanced, star-connected, three-phase load at unity power-factor is $3E_pI$, where E_p is the phase voltage and I the line current. But $E_p = 1/3 \sqrt{3} E$ where E is the line voltage and therefore the power is $\sqrt{3} EI$ in terms of the line voltage and line current.

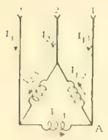


FIG. 29—DELTA CONNECTED LOAD

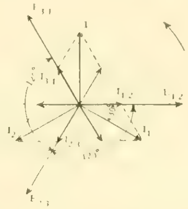


FIG. 30—VECTOR DIAGRAM OF A DELTA CONNECTED LOAD

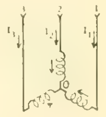


FIG. 31—STAR CONNECTED LOAD

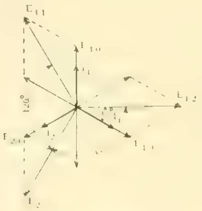


FIG. 32—VECTOR DIAGRAM OF A STAR CONNECTED LOAD

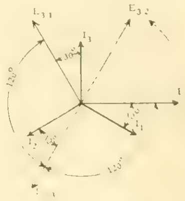


FIG. 33—VECTOR DIAGRAM OF CIRCUIT SHOWN IN FIG. 28

By comparing the results obtained for the delta and star-connected arrangements, it is seen that for both cases the expression for power is the same, and the line currents are 30 degrees behind the line voltages. These results are correct for any balanced three-phase load.

A group of meters is shown in Fig. 28 for a three-phase, three-wire circuit, which is very commonly used in practice. A simple vector diagram for the circuit is shown in Fig. 33 in which $E_{1\,2}$, $E_{2\,3}$ and $E_{3\,1}$ represent the line voltages and I_1, I_2 and I_3 the line currents 30 degrees behind the line voltages. When but two current transformers are used, one is generally connected in line *1* and the other in line *3*, Fig. 28. It is then more convenient to consider the voltage in phase *2* when in the direction from line *3* to line *2* than from *2* to *3*, and therefore $E_{3\,2}$, 180 degrees from $E_{2\,3}$ is shown in the vector diagram and the positive directions of currents through the voltage coils of the meters, as indicated by the small arrows in Fig. 28, are on the basis of using voltage $E_{3\,2}$. The static ground detector has three condensers, one being connected to each line, so that the detector will indicate which line becomes grounded when a ground occurs on the system. The frequency meter is connected to one phase, as the indication thus given is correct for the entire three-phase circuit. One voltmeter is used which, by means of the voltmeter switch, may be connected to any of the three phases. The development of the voltmeter switch shows how the connections are made for the different positions. For the off position, all the points are open and the voltmeter is entirely disconnected. For position *1*, points *1* and *2* are connected together and *3* and *4* are connected together so that the wire from the voltage transformers corresponding to line *1* is connected to one terminal of the voltmeter and the wire from the voltage transformers corresponding to line *2* is connected to the other, and the voltmeter gives the reading of the voltage between lines *1* and *2*. For position *2*, points *1* and *2* are connected together and points *4* and *5* are connected together, so that the wire from the voltage transformers corresponding to line *1* is connected to one terminal of the voltmeter and the wire from the voltage transformers corresponding to line *3* is connected to the other, and the voltmeter gives a reading of the voltage between lines *1* and *3*. For position *3*, points *2* and *3* are connected together and points *4* and *5* are connected together, so that the wire from the voltage transformers corresponding to line *2* is connected to one terminal of the voltmeter and the wire from the voltage transformers corresponding to line *3* is connected to the other and the voltmeter gives a reading of the voltage between lines *2* and *3*.

Three ammeters are used, which give readings of the currents in each of the three lines, so that their readings indicate how nearly the load on the system is balanced. The polyphase wattmeter gives an indication of the power being used in the circuit and the polyphase watthour meter registers the amount of energy consumed in the system. The power-factor or reactive factor meter gives an indication of the nature of the load with respect to power-factor.

In Fig. 34 is shown a group of meters on a three-phase, three-wire circuit, where one ammeter and one voltmeter are used. The development of the ammeter switch shows how the ammeter is connected to read the current in the respective lines for the different positions of the switch. For the *off* position, point *4* is open and points *1* and *3* are connected to point *2*, so that the currents from the current transformer in lines

1 and *3* combine and return through the ground wire from point *2* without any current going through the ammeter. For position *1*, point *1* is connected to point *4* and point 3 is connected to point *2*, so that the current from current transformer in line *1* flows to point *1* on the ammeter switch and out from point *4* through the ammeter (thus giving a reading of the current in line *1*) to the wire connected to point *2*, where it combines with the current from the current transformer in line *3*, which flows to point *3* on the ammeter switch and out on the wire from point *2*, and the combined currents return to the transformers on the ground wire. For position *2*, points *1* and *3* are connected to point *4* and point *2* is left open so that the currents from the current transformers in lines *1* and *3* are combined and flow out from point *4* on the ammeter switch through the ammeter (thus giving a reading equivalent to the current in line *2*) and return to the current transformers on the ground wire. For position *3*, point *3* is connected to point *4* and point *1* is connected to point *2*, so that the current from the current transformer in line *3* flows to point *3* on the ammeter switch and out from point *4* through the ammeter (thus giving a reading of the current in line *3*) where it combines with the current from the current transformer in line *1*, which flows to point *1* on the ammeter switch and out on the wire from point *2*, and the combined currents return to the transformers on the ground wire. The development of the voltmeter switch is as shown in Fig. 28. A polyphase graphic recording wattmeter is used for the circuit, which in addition to making the graphic record is provided with a pointer and scale so that it serves also as an indicating meter. A separate set of current transformers is provided for the polyphase watthour meter. This is necessary for light load accuracy.

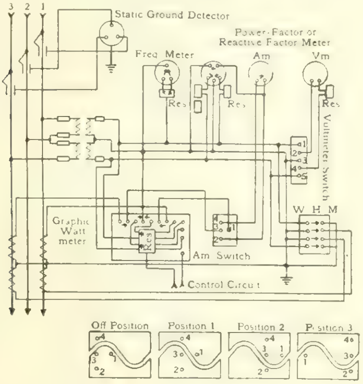


FIG. 34 METERS WITH VOLTMETER AND AMMETER SWITCHES

A group of meters is shown in Fig. 35 similar to that in Fig. 34, except that the voltage of the circuit is low enough that voltage transformers are not necessary and, in addition to the other meters, a polyphase indicating wattmeter is used. The development of the voltmeter and ammeter switches are as shown in Figs. 28 and 34.

The vector diagram, Fig. 33, shows how the polyphase wattmeter and the watthour meter, each consisting of two single-phase elements, measure the total power in the three-phase circuit. The case of a balanced load at unity power-factor will be considered. The current from the current transformer in line *1* (represented in the vector diagram by I_1) flows through the right hand element of the wattmeter and the upper element of the watthour meter. The voltage impressed on the voltage coils of these elements is the line voltage represented by $E_{1\,2}$. The torque producing reaction in a wattmeter element is proportional only to the component of the current which is in phase with the voltage. As I_1 is 30 degrees out of phase with $E_{1\,2}$, the component of I_1 in phase with $E_{1\,2}$ is I_1 cos 30 or $1/2\sqrt{3}\,I_1$, and the power measured by the one element of each meter is $1/2\sqrt{3}\,E_{1\,2}\,I_1$ or for the balanced load is $1/2\sqrt{3}\,EI$, where E represents the three-phase line voltage and I the line current. The current from the current transformer in line *3* (represented vectorially by I_3) flows through the left hand element of the wattmeter and the lower element of the watthour meter. The voltage impressed on the voltage coils of these elements is the line voltage $E_{3\,2}$. I_3 is 30 degrees out of phase with $E_{3\,2}$ and, therefore, the power measured by these elements respectively is $1/2\sqrt{3}\,E_{3\,2}\,I_3$ or, omitting the sub-figures for the balanced three-phase load, is $1/2\sqrt{3}\,EI$. The total power measured by each meter is the sum of the measurements in the two elements or $\sqrt{3}\,EI$ which is correct for the three-phase circuit.

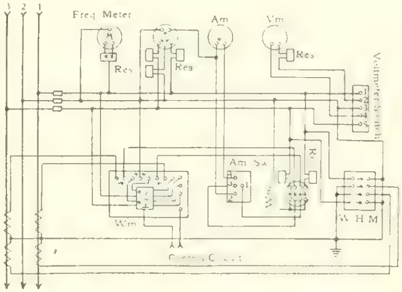
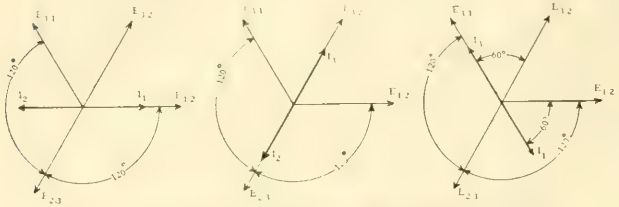


FIG. 35—METERS WITHOUT VOLTAGE TRANSFORMERS

The connections for the polyphase wattmeter and the watthour meter shown in Fig. 28 are correct for measuring the power, if the load consists of a single-phase circuit connected to any phase of the three-phase system. For simplicity, the loads will be assumed to have unity power-factor and only the polyphase wattmeter will be considered. When the load circuit is connected between lines *1* and *2*, current flows in these two lines but not in line *3*. The only current which flows through the wattmeter flows through the right-hand element from the current transformer in line *1*. A vector diagram for this case is shown in Fig. 36 in which I_1 represents the current in line *1* in phase with the line voltage $E_{1\,2}$, and I_2, 180 degrees from I_1, represents the current in line *2*. Since the voltage coil of the right-hand element of the wattmeter is connected to the voltage $E_{1\,2}$, the power measured by the right-hand element is $E_{1\,2}\,I_1$, which is correct for the single-phase circuit under consideration.

When the load circuit is connected between lines *2* and *3*, the power is measured by the left-hand element of the wattmeter, for the only current passing through the meter flows through the left-hand element from the current transformer in line *3*. A vector diagram for this case is shown in Fig. 37, in which I_3 represents the current in line *3* in phase with the line voltage $E_{3\,2}$, and I_2, 180 degrees from I_3, represents the current in line *2*. Current flows in both lines *2* and *3* but not in line *1*. Since the voltage coil of the left-hand element of the wattmeter is connected to the voltage $E_{3\,2}$, the power measured by this element is $E_{3\,2}\,I_3$ which is correct.



FIGS. 36, 37 AND 38 VECTOR DIAGRAMS FOR A SINGLE-PHASE LOAD

Fig. 36—Connected between lines 1 and 2.

Fig. 37—Connected between lines 2 and 3.

Fig. 38—Connected between lines 3 and 1.

When the load is connected between lines *3* and *1*, current flows in lines *3* and *1* but not in line *2*. Current flows through both elements of the wattmeter, as there is a current transformer in line *3* and line *1*. A vector diagram for this case is shown in Fig. 38, in which I_3 represents the current in line *3* and the current which flows through the left-hand element of the wattmeter, and I_1, 180 degrees from I_3, represents the current in line *1* and the current which flows through the right-hand element of the wattmeter. The voltage coil of the left-hand element is connected to the voltage $E_{3\,2}$, and the voltage coil of the right-hand element is connected to the voltage $E_{1\,2}$. It is seen from the vector diagram that I_3 is 60 degrees out of phase with $E_{3\,2}$, and I_1 is 60 degrees from $E_{1\,2}$. Therefore, the power measured by the left-hand element is $E_{3\,2}\,I_3\cos 60$ or $1/2\,E_{3\,2}\,I_3$, and the power measured by the right-hand element is $E_{1\,2}\,I_1\cos 60$ or $1/2\,E_{1\,2}\,I_1$. But current I_3 and I_1 are the same and voltages $E_{3\,2}$ and $E_{1\,2}$ are equal. Thus the total power as measured by the wattmeter is EI, where E is the line voltage and I the single-phase line current.

The discussions thus far have been on the basis of unity power-factor. In connection with the vector diagrams in Figs. 30 and 32 it was found that, for the condition of a balanced three-phase load at unity power-factor, the line currents were 30 degrees behind the line voltages. The diagrams in Figs. 39 and 40 are for balanced three phase loads, where the power-factor is not unity, but the currents in the phases of the load circuits lag behind the phase voltages by an angle ϕ. The power-factor is the cosine of the angle ϕ. The line currents in this case lag behind the line voltages by an angle $30° + \phi$. The power in the three-phase circuits is therefore $3E\,I_p\cos\phi$ for the delta-connected load, where E is the line voltage and I_p the phase current, or $3\,E_p\,I\cos\phi$ for the star-connected load, where E_p is the phase voltage and I the line current. But $I_p = 1/3\sqrt{3}\,I$ and $E_p = 1/3\sqrt{3}\,E$ and therefore the power in either case is $\sqrt{3}\,EI\cos\phi$. Single-phase loads do not need to to be considered, for they produce either balanced or unbalanced delta-connected loads. In the explanations, three-phase balanced loads are considered, because the fundamental principles involved may be more easily understood for a balanced load than for an unbalanced load and the vector diagrams are much simpler. However, a vector diagram can be constructed and the same principles applied in analyzing a circuit having a load at any power-factor or degree of unbalance.

By means of the diagrams in Figs. 39 and 40 it can be shown that the polyphase wattmeter, connected as in Fig. 28, correctly measures the power in the three-phase three-wire circuit when the power-factor is not unity. I_1, the current in line *1* and the current which flows through the right-hand element of the wattmeter, is $30° + \phi$ out of phase with the voltage $E_{1\,2}$ and therefore the power P_R measured by this element is $E_{1\,2}\,I_1\cos(30° + \phi)$. The power, P_L, measured by the left-hand element is $E_{3\,2}\,I_3\cos(30° + \phi)$, since the angle between $E_{3\,2}$ and I_3 is the difference between 30 degrees and ϕ. The total power measured by the meter is the algebraic sum of the measurements in the two elements or, omitting the sub-figures for the balanced load, is,—

$$P_R + P_L = E\,I\,[\cos(30° + \phi) + \cos(30° - \phi)]$$
$$= E\,I\,[1/2\sqrt{3}\cos\phi - 1/2\sin\phi + 1/2\sqrt{3}\cos\phi + 1/2\sin\phi] = \sqrt{3}\,E\,I\cos\phi.$$

This result is the same as the equation for the power in the three-phase circuit.

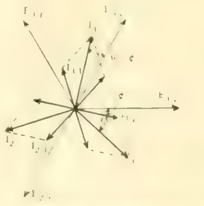


FIG. 39—VECTOR DIAGRAM OF A BALANCED DELTA CONNECTED LOAD

Where the power-factor is not unity.

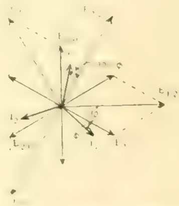


FIG. 40—VECTOR DIAGRAM OF A BALANCED STAR CONNECTED LOAD

Where the power-factor is not unity.

The equation just derived shows that the polyphase wattmeter does measure correctly the power in a three-phase circuit when the power-factor is not unity. The power measured by the meter will be determined here from a vector analysis of the circuit for several different angles of lag in order to observe the actions of the meter at such times. In each case, the results will be compared with the actual power in the circuit as calculated from the equation $P = \sqrt{3}\ E\ I\ cos\ \phi$ to show that the measurement by the meter is correct. Cases will be considered for a lag of 30 and 60 degrees, for an angle greater than 60 degrees, and for 90 degrees.

30 Degrees Lag—In Fig. 41 a vector diagram is shown for a balanced three-phase load where the current lags 30 degrees. The three line currents are represented by I_1, I_2 and I_3 30 degrees behind the positions they would have for unity power-factor, which are indicated by the dotted vectors I'_1, I'_2 and I'_3. In the right-hand element of the wattmeter, the current I_1, is 60 degrees behind the voltage $E_{1\,2}$, and the power measured by this element is $E_{1\,2}\,I_1\,cos\ 60° = 1/2\ E_{1\,2}\,I_1$. In the left-hand element, the current I_3 is in phase with the voltage $E_{3\,2}$ and the power measured by this element is $E_{3\,2}\,I_3$. The sum of the measurements in the two elements is $1/2\ E_{1\,2}\,I_1 + E_{3\,2}\,I_3$ or, for the balanced load, is $3/2\ E\ I$, where E is the line voltage and I the line current.

60 Degrees Lag—A vector diagram is shown in Fig. 42 for a balanced three-phase load, where the current lags 60 degrees. There is no power in the right-hand element of the wattmeter, because the current I_1 is 90 degrees behind the voltage $E_{1\,2}$, and there is no component of I_1 in phase with $E_{1\,2}$. In the left-hand element, the current I_3 is 30 degrees behind the voltage $E_{3\,2}$, and the power measured by this element is $E_{3\,2}\,I_3\ cos\ 30$ or, for the balanced load, is $1/2\sqrt{3}\ E\ I$.

Lag Between 60 and 90 Degrees—In Fig. 43 is shown a vector diagram for a balanced three-phase load where the current lags by an angle greater than 60 degrees represented by $60° + \alpha$ $(\alpha = \phi - 60)$. In the right-hand element of the wattmeter, the current I_1 is $60° - \alpha + 30°$ or $90° + \alpha$ behind $E_{1\,2}$ and the power measured by this element is $E_{1\,2}\,I_1$, $cos\ (90° + \alpha)$ or omitting the sub-figures for the balanced load and writing the expression in terms of the angle α is $-\ E\ I\ sin\ \alpha$. It is evident from the vector diagram that, when the current I_1 is more than 90 degrees behind $E_{1\,2}$, the component of I_1 (obtained by projecting the vector I_1 on the line of the vector $E_{1\,2}$) is in the opposite direction with reference to $E_{1\,2}$, and the torque producing reaction in the right-hand element is in the reverse direction. Therefore, the power measurement is negative, as indicated by the minus sign. In the left-hand element, the current I_3 is $30° + \alpha$ behind $E_{3\,2}$, and the power measured by this element is $E_{3\,2}\,I_3\ cos\ (30° + \alpha) = E_{3\,2}\,I_3\ (1/2\sqrt{3}\ cos\ \alpha - 1/2\ sin\ \alpha) = 1/2\ E_{3\,2}\,I_3\ (\sqrt{3}\ cos\ \alpha - sin\ \alpha)$ or for the balanced load is $1/2\ E\ I\ (\sqrt{3}\ cos\ \alpha - sin\ \alpha)$. Since the torque producing reaction in the right-hand element is in the reverse direction from that in the left-hand element, the total power measured by the meter is given by the algebraic sum of the measurements in the two elements, or $1/2\ E\ I\ (\sqrt{3}\ cos\ \alpha - sin\ \alpha) - E\ I\ sin\ \alpha = 1/2\ E\ I\ (\sqrt{3}\ cos\ \alpha - 3\ sin\ \alpha) = 1/2\sqrt{3}\ E\ I\ (cos\ \alpha - \sqrt{3}\ sin\ \alpha)$. The power in the circuit for a current lagging by an angle $60° + \alpha$ is $P = \sqrt{3}\ E\ I\ cos\ (60° + \alpha) = \sqrt{3}\ E\ I\ (1/2\ cos\ \alpha - 1/2\sqrt{3}\ sin\ \alpha) = 1/2\sqrt{3}\ E\ I\ (cos\ \alpha - \sqrt{3}\ sin\ \alpha)$ which is the same as the meter measures.

90 Degrees Lag—A vector diagram is shown in Fig. 44 for a balanced three-phase load where the current lags by the maximum angle of 90 degrees. In the right-hand element of the wattmeter, the current I_1 is 120 degrees behind $E_{1\,2}$ and the power measurement is $E_{1\,2}\,I_1\ cos\ 120 = E_{1\,2}\,I_1\ cos\ (90 + 30) = -\ E_{1\,2}\,I_1\ sin\ 30° = -\ 1/2\ E_{1\,2}\,I_1$ or, for the balanced load, is $-\ 1/2\ E\ I$ which is negative, as indicated by the minus sign. In the left-hand element, I_3 is 60 degrees behind $E_{3\,2}$ and the power measurement is $E_{3\,2}\,I_3\ cos\ 60 = 1/2\ E_{3\,2}\,I_3$, or for the balanced load is $1/2\ E\ I$. Then the total power measurement given by the algebraic sum of $1/2\ E\ I$ and $-\ 1/2\ E\ I$ is zero, which is correct.

It has been shown that, for lagging currents, when the angle of lag becomes 60 degrees, the measurement in the right-hand element is zero and all the power is measured by the left-hand element, and for angles of lag greater than 60 degrees, the measurement is negative in the right-hand element. When the angle of lag becomes 90 degrees, the negative measurement in the right-hand element is equal to the positive measurement in the left-hand element and the result is zero. If the current leads instead of lags, it can be seen from the vector diagrams that the action of the elements is just the reverse. Angles of lag or lead of greater than 90° indicate a reversal of direction of the flow of power.

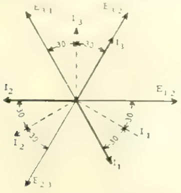


FIG. 41—A CURRENT LAG OF 30 DEGREES

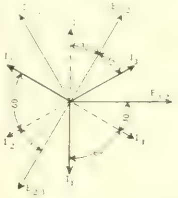


FIG. 42—A CURRENT LAG OF 60 DEGREES

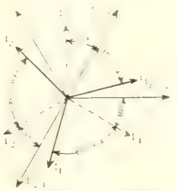


FIG. 43—A CURRENT LAG OF 60 DEGREES PLUS α

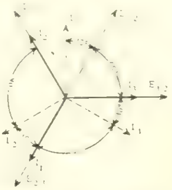


FIG. 44—A CURRENT LAG OF 90 DEGREES

Electrical Characteristics of Transmission Circuits-VIII

Performance of Long Transmission Lines (Graphical Solution)

Wm. Nesbit

THE E.M.F. of self-induction in a transmission circuit may either add to or subtract from the impressed voltage at the sending end, depending upon the relative phase relations between the current and the voltage at the receiving end of the circuit. This is illustrated by means of voltage vectors in Fig. 20, in which the phase of the current is assumed to be constant in the horizontal direction indicated by the arrow on the end of the current vector. The voltage at the receiving end is also assumed as constant at 100 volts. The vector representing the receiving end voltage (E_r = 100 volts) is shown in two positions corresponding to leading current, two positions corresponding to lagging current and in one position corresponding to unity power-factor. The components *IR* and *IX* of the supply voltage necessary to overcome the resistance *R* and the reactance *X* (e.m.f. of self-induction) of the circuit are assumed to be 10 volts and 20 volts respectively. Since the current is assumed as constant, *IX* and *IR* are also constant. The impedance triangle of the voltage components required to overcome the combined effect of the resistance and the reactance of this circuit is therefore constant. It is shown in five different positions about the semicircle, corresponding to five different load power-factors. The voltage E_s at the sending-end required to maintain 100 volts at the receiving-end is indicated for each of the five positions of the impedance triangle.

Counter-clockwise rotation of the vectors will be considered as positive. This means that when the current is lagging behind the impressed e.m.f., the voltage vector will be in the forward or leading direction from the current vector as indicated by the arrow. When the current leads the impressed voltage, the voltage vector will be in the opposite, or clockwise direction from the current vector. In other words, assuming the vectors all rotating at the same speed about the point *O* in a counter-clockwise direction, the current vector will be behind the voltage vector when the current is lagging and ahead of it when the current is leading.

The alternating magnetic flux surrounding the conductors, resulting from current flowing through them, generates in them a counter e.m.f. of self-induction. This e.m.f. of self-induction has its maximum value when the current is passing through zero and is therefore in lagging quadrature with the current. On the diagrams an arrow in the line *IX*, indicates the direction of the e.m.f. of self-induction. It will be seen that since the direction of the current is assumed constant, the e.m.f. of self-induction acts downward in all five impedance diagrams. The sending-end voltage is therefore opposed or favored by this self-induced voltage (see arrows) to a greater or less extent depending upon the power-factor of the load. Thus at lagging loads of high power-factor, the self-induced voltage acts approximately at right angles to the sending-end voltage, and therefore requires a small component of the sending-end voltage to balance or neutralize its effect. As the power-factor of the receiving-end load decreases in the lagging direction (upper quadrant of diagram) the sending-end voltage swings around more nearly in line with the direction of the induced voltage, thus requiring a greater component of the sending-end voltage to counter-balance its effect. At zero power-factor lagging, the direction of the sending-end voltage and that of the induced e.m.f. are practically in opposition, (as indicated by the arrows), so that the component of the sending-end voltage required to overcome the induced voltage is a maximum, or nearly as much as the e.m.f. of self-induction. It is interesting to note that at zero lagging power-factor, when the effect of self-induction on line voltage drop reaches a maximum, the sending-end voltage component *IR* necessary to overcome the resistance of the circuit, (now nearly at right angles to the supply voltage), is a minimum. The reverse of these conditions is true for receiving-end loads of power-factors near unity.

Now consider receiving-end loads of leading power-factors, (lower quadrant of diagram). It will be seen that the e.m.f. of self-induction does not now oppose the sending-end voltage (indicated by direction of the arrows) but has a direction more or less parallel to that of the sending-end voltage. At high leading power-factors, the e.m.f. of self-induction has little effect on the sending-end voltage, but as zero leading power-factor is approached these two e.m.f.'s more nearly come in phase with each other. At zero power-factor leading, the e.m.f. of self-induction adds almost directly to the sending-end voltage.

It will be seen, therefore, that for receiving-end loads of lagging power-factor, the sending-end voltage is greater than the receiving-end voltage, by an amount necessary to overcome the resistance and self-induction of the circuit. For receiving-end loads of leading power-factor, the sending-end voltage is less than the receiving-end voltage, for the reason that the e.m.f. of self-induction is in such a position as to assist the sending-end voltage.

The following values from Fig. 20 illustrate these conditions:

Power-Factor of Receiving End Load	Supply Voltage
0 percent lagging	120.4
80 percent lagging	120.4
100 percent	111.8
80 percent leading	98.5
0 percent leading	80.6

The condition of leading power-factor at the receiving-end would be unusual in practice, since the power-factor of receiving-end loads is usually lagging. In cases, however, where condensers are used for voltage or power-factor control, the power-factor at the receiving-end may be leading. If the circuit were without inductance, there could be no rise in voltage at the receiving-end, for in such a case, *IX* of the diagram would disappear, and the voltage drop would be the same as with direct current. All alternating-current circuits are inductive, and the greater their inductance, the greater will be the voltage drop, or the voltage rise along the circuit.

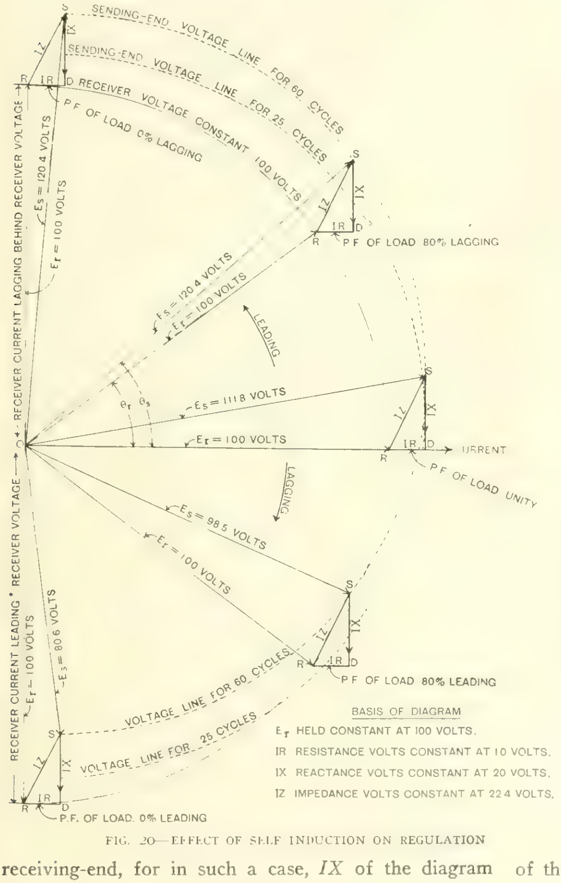

SENDING-END VOLTAGE LINE FOR 60 CYCLES
SENDING-END VOLTAGE LINE FOR 25 CYCLES
RECEIVER VOLTAGE CONSTANT 100 VOLTS
P F OF LOAD 0% LAGGING
RECEIVER CURRENT LAGGING BEHIND RECEIVER VOLTAGE
Es = 120.4 VOLTS
Er = 100 VOLTS
S
R
D
IR
IX
IZ
P F OF LOAD 80% LAGGING
Es = 120.4 VOLTS
Er = 100 VOLTS
LEADING
θr θs
Es = 111.8 VOLTS
Er = 100 VOLTS
O
CURRENT
P F OF LOAD UNITY
LAGGING
Es = 98.5 VOLTS
Er = 100 VOLTS
P F OF LOAD 80% LEADING
RECEIVER CURRENT LEADING RECEIVER VOLTAGE
Er = 100 VOLTS
Es = 80.6 VOLTS
VOLTAGE LINE FOR 60 CYCLES
VOLTAGE LINE FOR 25 CYCLES
P.F. OF LOAD 0% LEADING
BASIS OF DIAGRAM
Er HELD CONSTANT AT 100 VOLTS.
IR RESISTANCE VOLTS CONSTANT AT 10 VOLTS.
IX REACTANCE VOLTS CONSTANT AT 20 VOLTS.
IZ IMPEDANCE VOLTS CONSTANT AT 22.4 VOLTS.

FIG. 20—EFFECT OF SELF INDUCTION ON REGULATION

Any alternating-current circuit may be looked upon as containing three active e.m.f.'s out of phase with each other. In addition to the impressed e.m.f. at the sending-end, there are two e.m.f.'s of self-induction, one as the result of the receiving-end current and lagging 90 degrees behind it and the other as the result of the line charging current and lagging 90 degrees behind it. These two combine at an angle, with each other and with the impressed e.m.f. at the sending-end.

CHARGING CURRENT

Conductors of a circuit, being separated by a dielectric (such as air, in overhead circuits, or insulation in cables), form a condenser. When alternating-current flows through such a circuit, current (known as charging current) virtually passes from one conductor through the dielectric to the other conductors, which are at a different potential. This current is in shunt with the circuit, and differs from the current which passes between conductors over the insulators etc. (leakage current) or through the air (corona effect) only in that the charging current leads the voltage by 90 degrees, whereas the leakage current is in phase with the voltage.

For a given spacing of conductors, the charging current increases with the voltage, the frequency and the length of the circuit. For long high-voltage circuits, particularly at 60 cycles per second, the charging current may be as much as the full-load current of the circuit, or more. In some cases of long 60 cycle circuits, where a comparatively small amount of power is to be transmitted, it is necessary to limit the voltage of transmission, in order that the charging current may not be so great as to overload the generators. This charging current, being in leading quadrature with the voltage, represents nearly all reactive power, but it is just as effective in heating the generator windings as if it represented active power. On the other hand, it combines with the receiving-end current at an angle (depending upon the power-factor of the receiver load) in such a manner that the addition of the full-load receiving-end current, in extreme cases, may not greatly increase the sending-end current. In other words (if the charging current is near full-load current) the current at the generator end may not increase much when full load at the receiver end is added, over what it is when no load is taken off at the receiving-end.

Since the e.m.f. of self-induction due to the charging component is proportional to the charging current, its effect upon the voltage regulation of the circuit will also be proportional to the charging current. For a short low-voltage circuit, the charging current is so small that its effect on voltage regulation may be ignored. On the longer circuits, especially long 60 cycle circuits, such as will be considered later, its effect must be given careful consideration.

VARIATION IN CURRENT AND VOLTAGE ALONG THE CIRCUIT

It was explained above and illustrated in Fig. 20 that with a receiving-end load of leading power-factor, the voltage at the sending-end of the circuit might be less than that at the receiving-end. It was shown that the e.m.f. of self-induction, resulting from the leading current, tends to raise the voltage along the circuit. This boosting effect of the voltage is entirely due to the leading component of the load current.

If, now, it is assumed that the power-factor of the receiving-end load is 100 percent, there will be no leading component in the load current, and therefore there can be no boosting of the voltage due to the load current. Since, however, all circuits have capacitance, and since the current is alternating, charging current will flow into the line and this being a leading current, the same tendency to raise the voltage along the circuit will take place as is illustrated by Fig. 20.

The upper part of Fig. 21 is intended to give a physical conception of what takes place in an alternating-current circuit. As the load current starts out from the sending-end, and travels along the conductor, it meets with ohmic resistance. This is represented by r in Fig. 21. It also meets with reactance in quadrature to the current. This is represented by jx in the diagram. Superimposed upon this load current is a current flowing from one conductor to the others, in phase with the voltage at that point and representing true power. This current is the result of leakage over insulators and of corona effect between the conductors. It is represented by the letter g in the diagrams. Then there is the charging current in leading quadrature with the voltage. This current does not consume any active power except that necessary to overcome the resistance to its flow.

In Fig. 21 the four linear constants of the alternating-current circuit, r representing the resistance, jx representing the reactance, g representing the leakage and b representing the susceptance, are shown as located, or lumped, at six different points along the circuit. This is as they would appear in an artificial circuit divided into six units. In any actual line, these four constants are distributed quite evenly throughout the length of the circuit.

VOLTAGE AND CURRENT DISTRIBUTION FOR PROBLEM X

The effect of the charging current flowing through the inductance of the circuit gives rise to a very interesting phenomenon. In order to illustrate this effect, the current and voltage distribution for a 60 cycle, 1000 volt, three-phase circuit, 300 miles long, is plotted in Fig. 21. This circuit will be referred to as problem X. In such a long 60 cycle circuit, this phenomenon is quite pronounced; so that such a problem serves well as an illustration. The voltage and the current have been determined for points 50 miles apart along the circuit. Values for both the current and the voltage under zero load, also under load conditions have been plotted. The load conditions refer to a receiving-end load of 18 000 kv-a, at 90 percent power-factor, lagging, 60 cycle three-phase. The voltage is assumed as being held constant 104 000 volts at the receiving-end, for both zero and full-load conditions.

Zero-Load Conditions—Without any load being taken from the circuit, it will be seen that the charging current at the sending-end approaches in value that established when under full load; i.e., 94.75 amperes. The charging current drops down to approximately 50 amperes at the middle, and to zero at the receiving-end of the unloaded circuit. The lower full line curve shows how this current is distributed along the circuit. Starting at zero, at the receiving-end of the circuit, it increases as the sending-end of the circuit is approached, at which point it reaches its maximum value of 87.89 amperes. The voltage distribution under zero-load conditions is some-what opposite to that of the current distribution. That is the voltage (104 000 volts at the receiving-end) keeps falling lower until it reached a value of 84 676 at the sending-end. It should be noted that the voltage curve for zero load condition drops down rapidly as the sending-end is approached. The reason for this is the large charging current flowing through the inductance of the circuit at this end of the circuit. The larger the charging current the greater the resultant boosting of the receiving-end voltage.

Load Conditions—When 16 000 kv-a at 90 percent power-factor lagging is taken from the circuit at the receiving-end, the current at this end goes up to 90.92 amperes. As the supply end is approached the current becomes less, reaching its lowest value (approximately 83 amperes) in the middle of the circuit. At the supply end it is 94.75 amperes, which is less than it is at the receiver end. Thus the full line representing the current in amperes along the circuit assumes the form of an arc, bending downward in the middle of the circuit. The shape of this current curve is dependent upon the relative values of the leading and lagging components of the current at points along the circuit. The reason that the current is a minimum near the middle of the circuit, is because this is the point where the lagging current of the load and the leading charging current of the circuit balance or neutralize each other, and the power-factor is therefore unity. Starting at the receiving-end, the power-factor is 90 percent lagging. As the middle of the circuit is approached, the increasing charging current neutralizes an increasing portion of the lagging component of the load current. Near the middle of the circuit, this lagging component is entirely neutralized, and the power-factor therefore rises to unity. Passing the middle and approaching the sending-end there is no more lagging component to be neutralized, and the increasing charging current causes a decreasing leading power-factor which, when the sending-end is reached, becomes 93.42 percent leading. It will, therefore, be seen that the power-factor as well as the current and voltage varies throughout the length of the circuit.

The voltage distribution under load condition is indicated by the top broken line. In order that the receiving-end voltage may be maintained constant at 104 000 volts, the voltage at the sending-end will vary from 84 676 volts at zero load to 122 370 volts at the assumed load.

THE AUXILIARY CONSTANTS

With the impedance methods considered under the general heading of "Short Transmission Lines" the current was considered as of the same value throughout the circuit, and the voltage drop along the circuit was considered as proportional to the distance. These assumptions, which are permissible in case of short lines, are satisfied by simple trigonometric formulas.

The rigorous solution for circuits of great electrical length accurately takes into account the effect produced by the non-uniform distribution of the current and the voltage throughout the length of the circuit. This effect will hereafter be referred to as the *distribution effect* of the circuit, and may be taken into account through the application of the so called auxiliary constants of the circuit.

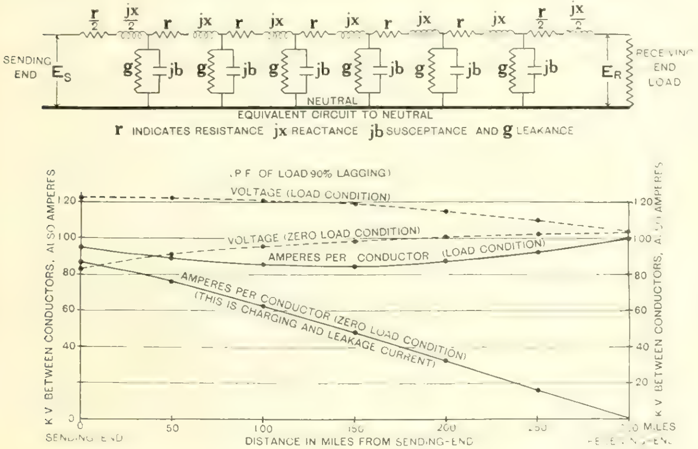


FIG. 21—DIAGRAMS OF TRANSMISSION CIRCUIT—PROBLEM X

300 miles long, 104 000 volts delivered, 60 cycle. The upper diagram gives a physical conception of the conditions along the line. The curves show the variation in current and voltage along the circuit.

The auxiliary constants *A*, *B* and *C* of the circuit are functions of its physical properties, and of the frequency only. They are entirely independent of the voltage or current of the circuit. The various solutions for long transmission circuits are in effect schemes for determining the values of these three auxiliary constants. Mathematically they may be calculated, by hyperbolic functions or by their equivalent convergent series. Graphically they may be obtained to a high degree of accuracy from the accompanying Wilkinson Charts for overhead circuits not exceeding 300 miles in length. Having determined the values for these three constants for a given circuit, the remainder of the solution is just as simple as for short lines It is only necessary to apply any desired load conditions to these constants and plot the results by vector diagrams.

DIAGRAM OF THE AUXILIARY CONSTANTS

In Fig. 22 are shown voltage and current diagrams representing the application of the auxiliary constants to the solution of transmission circuit problems. To construct the voltage vector diagram, the two auxiliary constants *A* and *B* are required, and to construct the current vector diagram, constants *A* and *C* are required.

Since these diagrams are based upon one volt and one ampere at the receiving-end, it is necessary to multiply the values of the auxiliary constants by the volts or the amperes at the receiving-end, in order to apply the auxiliary constants to a specific problem. Since the diagrams are shown corresponding to unity power-factor, it will also be necessary to change the position of the impedance and charging current triangles in case the power-factor differs from unity. This will be explained later.

Constants a_1 and a_2—Referring to the voltage diagram, Fig. 22, if the line is electrically short the charging current, and consequently its effect upon the voltage regulation is small. In such a case the auxiliary constant a_1 would be unity, and the auxiliary constant a_2 would be zero. In other words, the impedance diagram would (for a power-factor of 100 percent) be built upon the end of the vector *ER*, the point *O* coinciding with the point *R*. In such a case, the voltage at the sending end, at zero load, would be the same as that at the receiving-end. If the circuit contains appreciable capacitance, the e.m.f. of self-induction, resulting from the charging currents which will flow, will result in a lower voltage at zero load at the sending-end than at the receiving-end of the line, as previously explained. Obviously, the load impedance triangle must be attached to the end of the vector representing the voltage at the sending-end of the circuit at zero load. This is the vector *EO* of the voltage diagram, Fig. 22. This voltage diagram corresponds to that of a 60 cycle circuit, 300 miles in length. In such a circuit, the effect of the charging current is sufficiently great to cause the shifting of the point *O* from *R* (in a short line) to the position shown in Fig. 22. In other words, the voltage at zero load at the sending-end has shifted from *ER* for circuits of short electrical length, to *EO* for this long 60 cycle circuit. The auxiliary constants a_1 and a_2, therefore, determine the length and position of the vector representing the sending-end voltage at zero load. Actually, the constant a_2 represents the volts resistance drop due to the charging current, for each volt at the receiving-end of the circuit. That is, the line OF equals approximately one-half the charging current times the resistance R, taking into account, of course, the distributed nature of the circuit. If the circuit is short, it would be sufficiently accurate to assume that the total charging current flows through one-half of the resistance of the circuit. To make this clear, it will be shown later that, for problem X, the resistance per conductor $R = 105$ ohms and the auxiliary constant $C_2 = 0.001463$. Thus, this line will take 0.001463 ampere charging current, at zero load, for each volt maintained at the receiving-end, and since $OF =$ approximately $I_c \times \frac{R}{2}$ we have $OF\ (a_2) = 0.001463 \times \frac{105}{2} = 0.0768075$. The exact value of a_2 as calculated rigorously, taking into account the distributed nature of the circuit, is 0.076831. Since the charging current is in leading quadrature with the voltage ER, the resistance drop OF due to the charging current is also at right angles to ER, as in Fig. 22.

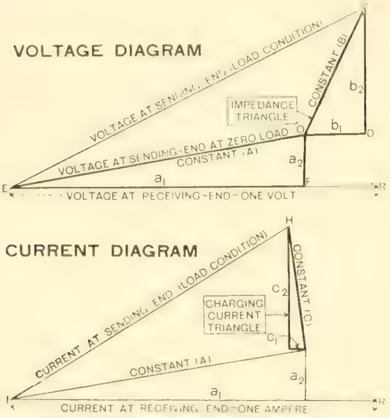

VOLTAGE DIAGRAM
VOLTAGE AT SENDING-END (LOAD CONDITION)
CONSTANT (B)
IMPEDANCE TRIANGLE
VOLTAGE AT SENDING-END AT ZERO LOAD
CONSTANT (A)
b2
b1
a2
a1
E
O
D
F
R
VOLTAGE AT RECEIVING-END—ONE VOLT
CURRENT DIAGRAM
CURRENT AT SENDING END (LOAD CONDITION)
CONSTANT (C)
CHARGING CURRENT TRIANGLE
c2
c1
CONSTANT (A)
a2
a1
H
I
R
CURRENT AT RECEIVING END—ONE AMPERE

FIG. 22—DIAGRAMMATIC REPRESENTATION OF AUXILIARY CONSTANTS OF A TRANSMISSION CIRCUIT

The vectors are based upon one volt and one ampere being delivered to the receiving end at unity power-factor. These diagrams correspond to those of a long circuit.

The length of the line FR or $(1-a_1)$, represents the voltage consumed by the charging current flowing through the inductance of the circuit. This may also be expressed with small error if the circuit is not of great electrical length as $I_c \times \frac{X}{2}$. The reactance per conductor for problem X is 249 ohms. Therefore $FR = 0.001463 \times \frac{249}{2} = 0.182143$ and $a_1 = 1.000000 - 0.182143 = 0.817857$. The exact value for a_1 as calculated rigorously, taking into account the distributed nature of the circuit, is 0.810558. The vector FR, representing the voltage consumed by the charging current flowing through the inductance, is naturally in quadrature with the vector OF, representing the voltage consumed by the charging current flowing through the resistance of the circuit.

Constants b_1 and b_2 represent respectively the resistance and the reactance in ohms, as modified by the distributed nature of the circuit. The values for these constants, multiplied by the current in amperes at the receiver-end of the circuit, give the IR and IX volts drop consumed respectively by the resistance and the reactance of the circuit. To illustrate this, the values of R and X for problem X are $R = 105$ ohms and $X = 249$ ohms per conductor. The distribution effect of the circuit modifies these linear values of R and X so that

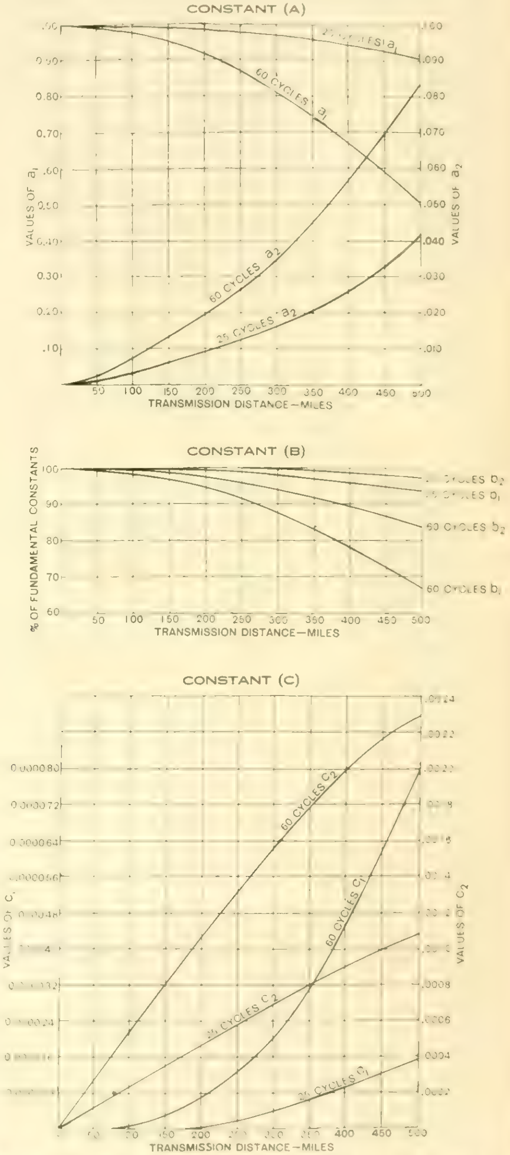


FIG. 23—VARIATION OF THE AUXILIARY CONSTANTS FOR CIRCUITS OF DIFFERENT LENGTHS

their effective values are $b_1 = 91.7486$ and $b_2 = 235.868$ ohms. The impedance triangle, as modified so as to take into exact account the distributed nature of the circuit, is therefore smaller than it would be if the circuit were without capacitance.

Constants c_1 and c_2 represent respectively conductance and susceptance in ohms as modified by the distributed nature of the circuit. The values for these constants, multiplied by the volts at the receiving-end of the circuit, give the current consumed respectively by the conductance and the susceptance of the circuit. To illustrate, the value of B for problem X is 0.001563 ohm per conductor. The distribution effect of the circuit modifies this fundamental value so that its effective value $c_2 = 0.001463$. The value of c_1 is so small that its effect is negligible for all except very long circuits. For power circuits it will usually be sufficiently accurate to neglect c_1. The value c_2 will in such cases represent the charging current at zero load per volt at the receiving-end. Thus c_2, multiplied by the receiving-end voltage, gives the charging current at zero load for the circuit. For problem X, $c_2 = 0.001463$, and this, multiplied by the receiving-end voltage to neutral 60 044 = 87.85 amperes charging current per conductor.

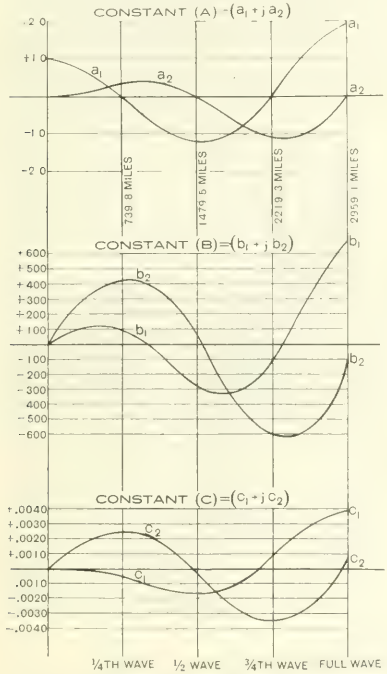


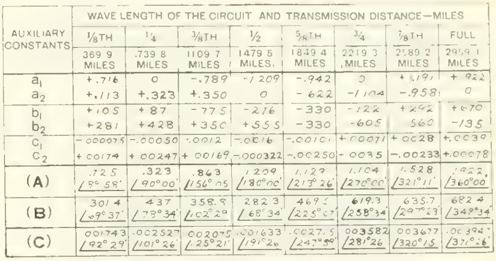
FIG. 24—VARIATION OF THE AUXILIARY CONSTANTS

For a 60 cycle circuit (problem X) up to full wave length.

VARIATION IN THE AUXILIARY CONSTANTS

The curves, Fig. 23, will serve to illustrate in a general way how the auxiliary constants vary for both 25 and 60 cycle circuits for lengths up to and including 500 miles. In other words these curves have been plotted from calculated values for these constants for certain circuits.

When the circuit is short, these constants do not vary materially from the linear constants of the circuit, but when the circuit becomes long, they depart rapidly, particularly if the frequency is high.



AUXILIARY CONSTANTS	WAVE LENGTH OF THE CIRCUIT AND TRANSMISSION DISTANCE—MILES							
	⅛TH	¼	⅜TH	½	⅝TH	¾	⅞TH	FULL
	369 9 MILES	.739 8 MILES	1109 7 MILES	1479 5 MILES.	1849 4 MILES	2219 3 MILES	2589 2 MILES	2959 1 MILES
a_1 a_2	+.716 +.113	0 +.323	-.789 +.350	-1 209 0	-.942 -.622	0 -1 104	+1.191 -.958	+.922 0
b_1 b_2	+105 +281	+87 +428	-77 5 +350	-216 +555	-330 -330	-122 -605	+292 560	+670 -135
c_1 c_2	-.000075 +.00174	-.00050 +.00247	-.0012 +.00169	-.0016 -.000322	-.00101 -.00250	+.00071 -.0035	+.0028 -.00233	+.0030 +.00078
(A)	.725 ∠8°58'	.323 ∠90°00'	.863 ∠156°05	1.209 ∠180°00'	1.127 ∠213°26'	1.104 ∠270°00'	1.528 ∠321°11'	.922 ∠360°00'
(B)	301 4 ∠69°37'	437 ∠78°34'	358.9 ∠102°29	282 3 ∠68°34'	469.5 ∠225°07'	619.3 ∠258°34'	635.7 ∠297°23'	682 4 ∠348°34'
(C)	.001743 ∠92°29'	.002527 ∠101°26'	.002075 ∠125°21'	.001633 ∠191°26	.002715 ∠247°59'	.003582 ∠281°26	.003677 ∠320°15	.003947 ∠371°26'

FIG. 25—VARIATION OF THE AUXILIARY CONSTANTS

For problem X up to full wave length.

The auxiliary constants have been calculated for problem X up to and including a full wave length, namely 2959 miles. Calculations were made only for distances representing each *1/8*th wave, that is each 370 miles. The results are tabulated in Fig. 25, and are plotted graphically in Fig. 24. It is interesting to note how these auxiliary constants vary with increasing negative and positive values as the circuit increases in length. A polar diagram is plotted in Fig. 26, indicating the manner in which the auxiliary constant A and its rectangular co-ordinates vary. Although these extreme variations are instructive and interesting, they are not encountered in power transmission circuits, although they will be in long distance telephone practice.

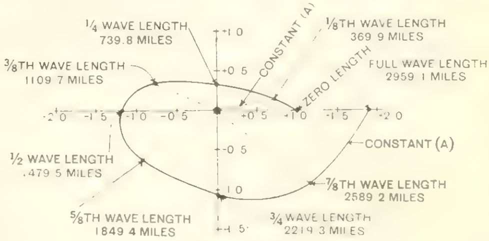


FIG. 26—POLAR DIAGRAM

Showing the variation of the auxiliary constant A for problem X, up to full wave length.

THE WILKINSON CHARTS

Mr. T. A. Wilkinson has prepared charts from which the auxiliary constants may be read directly, thus abridging a great amount of tedious mathematical calculation. These charts, are plotted for circuits of lengths up to and including 300 miles.*

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*Similar Charts by Mr. Wilkinson were published in the *Electrical World* for Mar. 16, 1918.

CHART V—WILKINSON CHART A

(FOR DETERMINING AUXILIARY CONSTANTS—ZERO LOAD VOLTAGE)

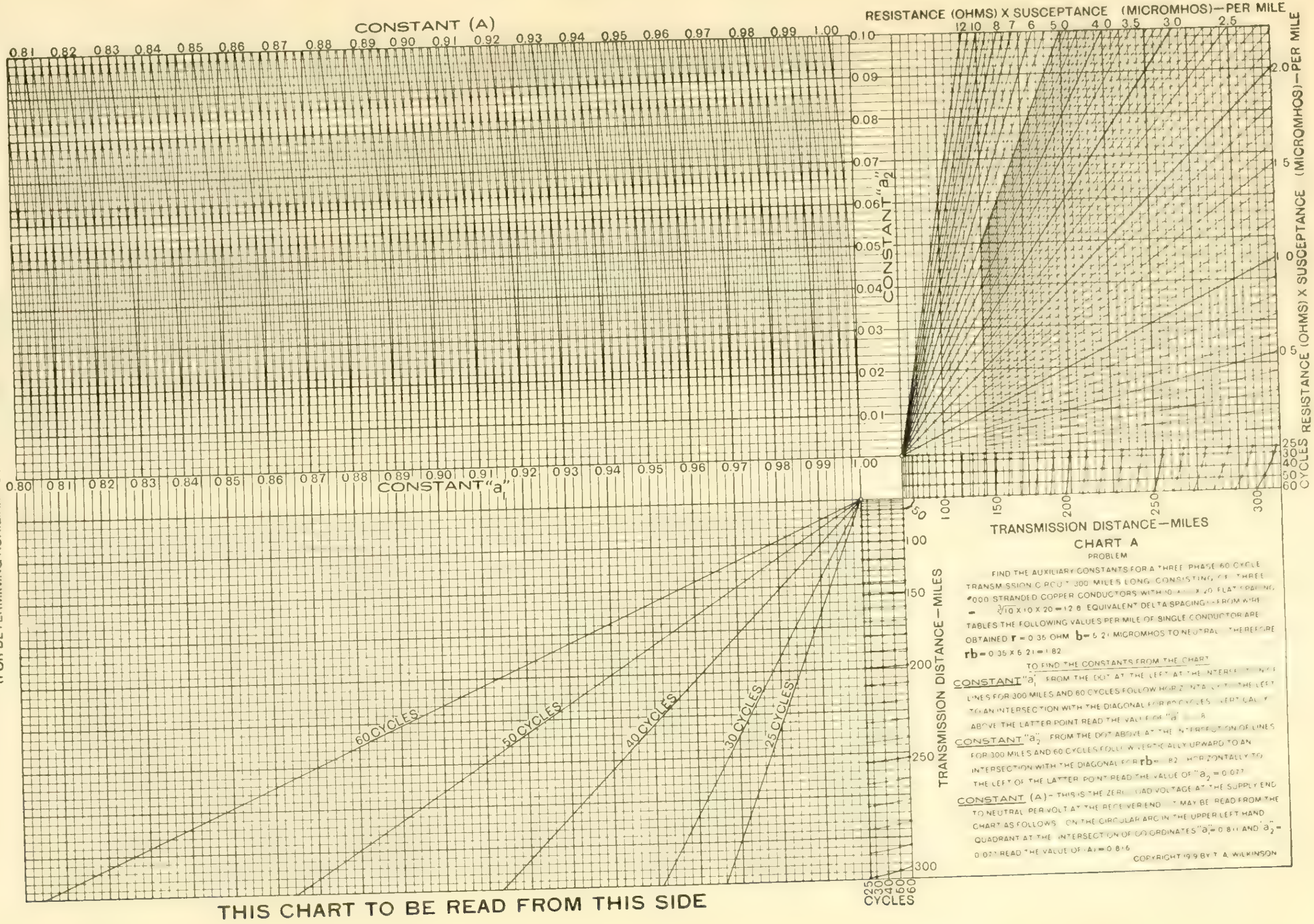

CHART A

PROBLEM

FIND THE AUXILIARY CONSTANTS FOR A THREE PHASE 60 CYCLE TRANSMISSION CIRCUIT 300 MILES LONG CONSISTING OF THREE #000 STRANDED COPPER CONDUCTORS WITH 10 [illegible] X 20 FLAT SPACING, $= \sqrt[3]{10 \times 10 \times 20} = 12.6$ EQUIVALENT DELTA SPACING. FROM WIRE TABLES THE FOLLOWING VALUES PER MILE OF SINGLE CONDUCTOR ARE OBTAINED **r** = 0.35 OHM **b** = 5.21 MICROMHOS TO NEUTRAL. THEREFORE

rb = 0.35 X 5.21 = 1.82

TO FIND THE CONSTANTS FROM THE CHART

CONSTANT "a_1" FROM THE DOT AT THE LEFT AT THE INTERSECTION OF THE LINES FOR 300 MILES AND 60 CYCLES FOLLOW HORIZONTALLY TO THE LEFT TO AN INTERSECTION WITH THE DIAGONAL FOR 60 CYCLES. VERTICALLY ABOVE THE LATTER POINT READ THE VALUE OF "a_1" [illegible]

CONSTANT "a_2" FROM THE DOT ABOVE AT THE INTERSECTION OF LINES FOR 300 MILES AND 60 CYCLES FOLLOW VERTICALLY UPWARD TO AN INTERSECTION WITH THE DIAGONAL FOR **rb** = 1.82. HORIZONTALLY TO THE LEFT OF THE LATTER POINT READ THE VALUE OF "a_2" = 0.077

CONSTANT (A)—THIS IS THE ZERO LOAD VOLTAGE AT THE SUPPLY END TO NEUTRAL PER VOLT AT THE RECEIVER END. IT MAY BE READ FROM THE CHART AS FOLLOWS: ON THE CIRCULAR ARC IN THE UPPER LEFT HAND QUADRANT AT THE INTERSECTION OF CO-ORDINATES "a_1" = 0.811 AND "a_2" = 0.077 READ THE VALUE OF (A) = 0.816

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CHART VI—WILKINSON CHART B

(FOR DETERMINING AUXILIARY CONSTANTS—LINE IMPEDANCE)

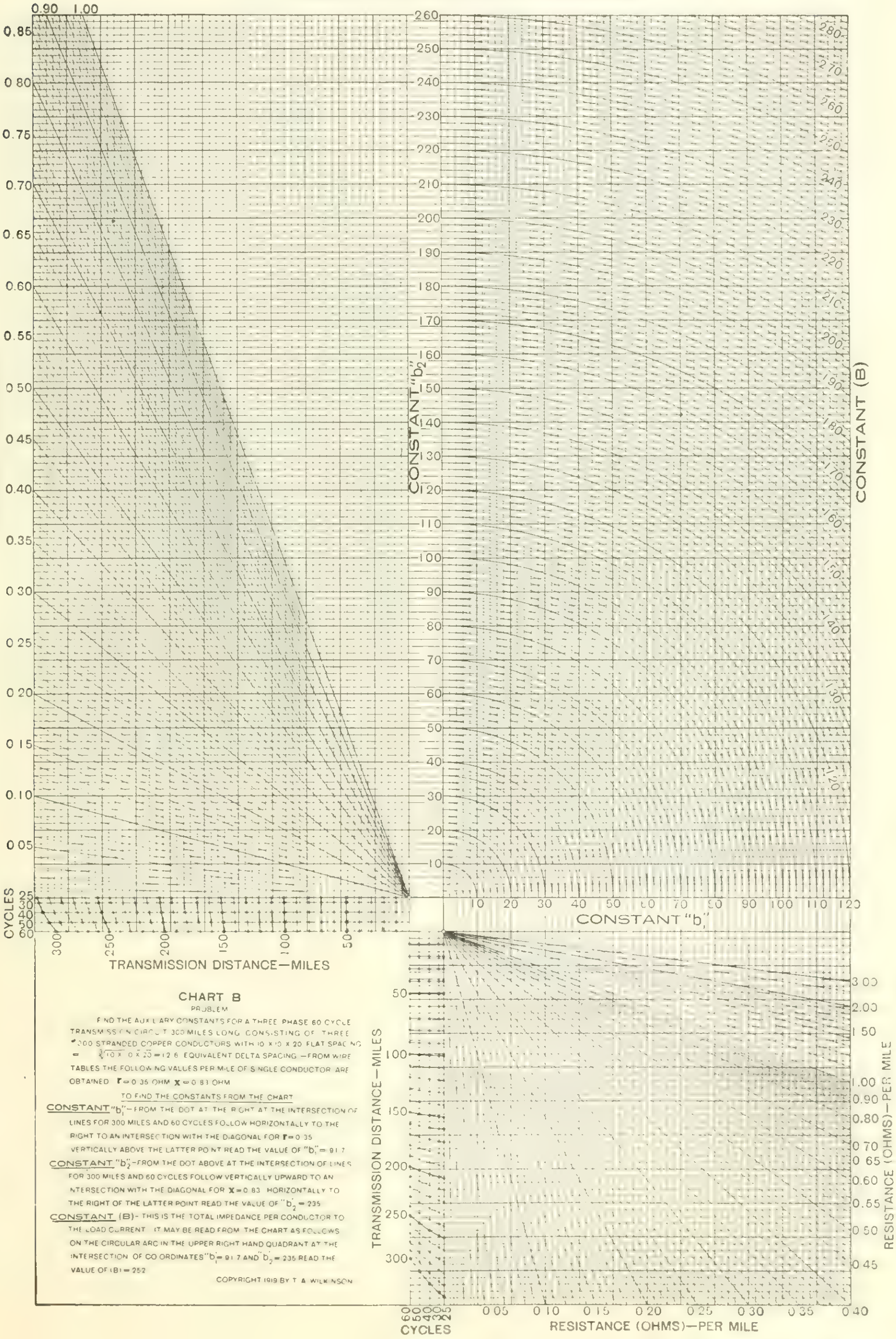

CHART B

PROBLEM

FIND THE AUXILIARY CONSTANTS FOR A THREE PHASE 60 CYCLE TRANSMISSION CIRCUIT 300 MILES LONG CONSISTING OF THREE #300 STRANDED COPPER CONDUCTORS WITH 10 X 10 X 20 FLAT SPACING = $\sqrt[3]{10 \times 10 \times 20} = 12.6$ EQUIVALENT DELTA SPACING —FROM WIRE TABLES THE FOLLOWING VALUES PER MILE OF SINGLE CONDUCTOR ARE OBTAINED **r** = 0.35 OHM **x** = 0.83 OHM

TO FIND THE CONSTANTS FROM THE CHART

CONSTANT "b_1''"—FROM THE DOT AT THE RIGHT AT THE INTERSECTION OF LINES FOR 300 MILES AND 60 CYCLES FOLLOW HORIZONTALLY TO THE RIGHT TO AN INTERSECTION WITH THE DIAGONAL FOR **r** = 0.35 VERTICALLY ABOVE THE LATTER POINT READ THE VALUE OF "b_1''" = 91.7

CONSTANT "b_2''"—FROM THE DOT ABOVE AT THE INTERSECTION OF LINES FOR 300 MILES AND 60 CYCLES FOLLOW VERTICALLY UPWARD TO AN INTERSECTION WITH THE DIAGONAL FOR **x** = 0.83 HORIZONTALLY TO THE RIGHT OF THE LATTER POINT READ THE VALUE OF "b_2'" = 235

CONSTANT (B)—THIS IS THE TOTAL IMPEDANCE PER CONDUCTOR TO THE LOAD CURRENT IT MAY BE READ FROM THE CHART AS FOLLOWS ON THE CIRCULAR ARC IN THE UPPER RIGHT HAND QUADRANT AT THE INTERSECTION OF CO ORDINATES "b_1'" = 91.7 AND "b_2'" = 235 READ THE VALUE OF (B) = 252

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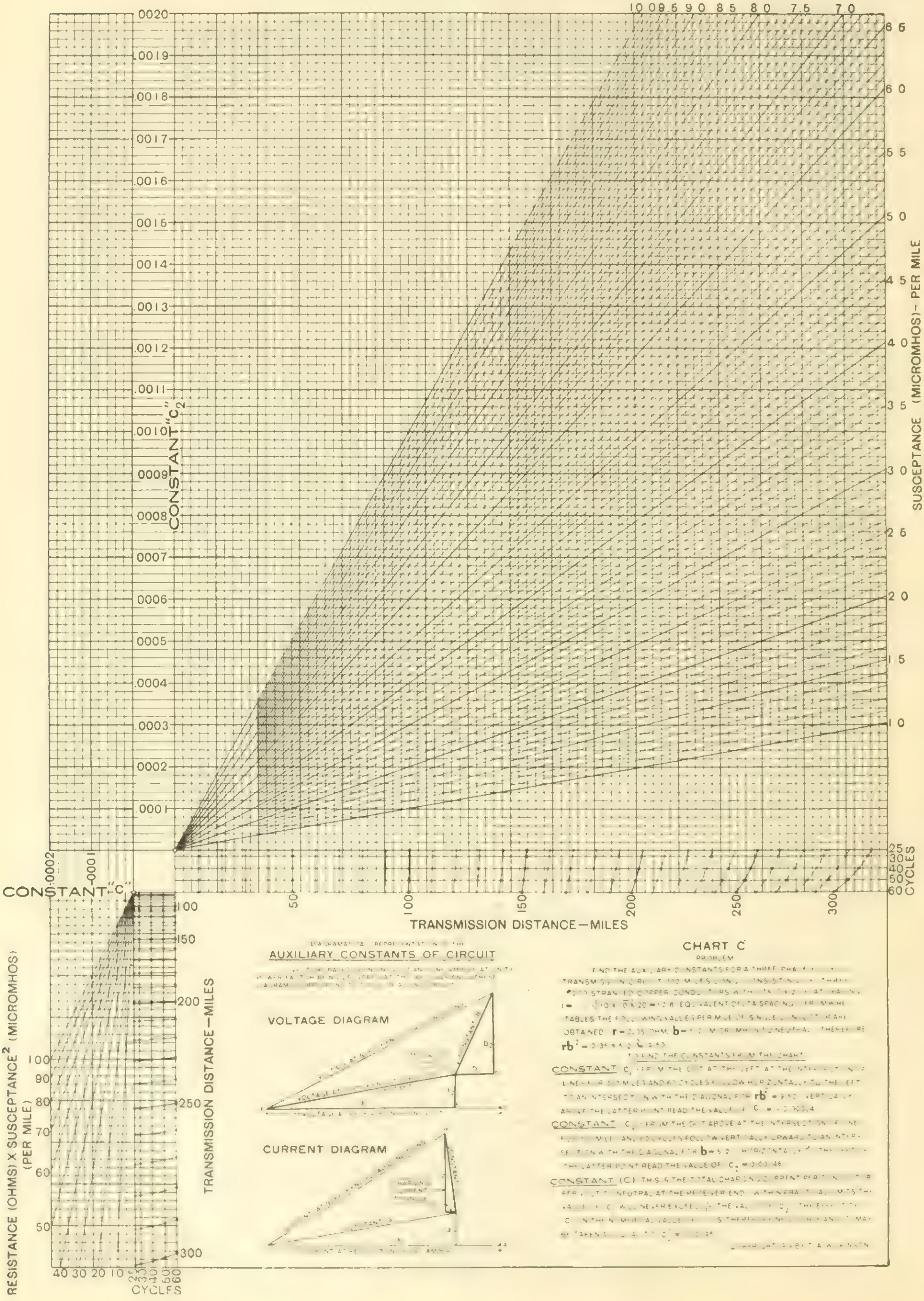
CHART VII—WILKINSON CHART C

(FOR DETERMINING AUXILIARY CONSTANTS—CHARGING CURRENT)



The reading of these charts is simplified by reason of the fact that all three charts are somewhat similar. In following any of them, the start is made from the intersection of the short arc representing length of circuit and the straight line representing the frequency. From this intersection a straight line is followed to a diagonal line and thence at right angles to the constant required. Thus in a few minutes the auxiliary constants of the circuit may be obtained directly from the chart, whereas by a mathematical solution from 15 minutes to an hour might be consumed in obtaining them. It is not, however, the time saved in obtaining these constants which is most important. The greatest advantage in this graphical solution for the auxiliary constants is that it not only abridges the use of a form of mathematics which the average engineer is inefficient in using, but it tends to prevent serious mistakes being made. In calculating these auxiliary constants by either convergent series or hyperbolic methods, an incorrect algebraic sign assigned to a number may cause a very serious error. Errors of magnitude are less likely to occur when using a comparatively simple graphical solution.

In order to determine the accuracy obtainable by a complete graphical solution, using the Wilkinson Charts for obtaining the auxiliary constants and vector diagrams for the remainder of the solutions, 48 problems were solved both graphically and mathematically. These problems consisted of circuits varying between 20 and 300 miles in length, and voltages varying between 10 000 and 200 000 volts. Twenty-four problems were for 25 cycle, and the same number for 60 cycle circuits. The maximum error in supply end voltage by the graphical solution employing a four times magnifying glass was one-fourth of one percent. A tabulation of the results as determined by various methods for these circuits will follow later.

APPLICATION OF TABLES

The application of the tables to long transmission lines follows, in general, the same plan as for short lines, published as Chart II, with such modifications as are produced by the effects of distributed capacitance and reactance. The procedure best suited for long transmission lines is shown in Chart VIII.

GRAPHICAL SOLUTION OF PROBLEM *X*

Problem X—Length of circuit 300 miles, conductors three No. 000 stranded copper spaced 10 by 10 by 20 feet (equivalent delta 12.6 feet) Temperature taken as 25 degrees C. Load conditions at receiving-end 18 000 kv-a, (16 200 kw at 90 percent power-factor lagging) 104 000 volts, three-phase, 60 cycles.

$$E_{rn} = \frac{104\,000}{1732} = 60\,046 \textit{ volts.}$$

$$I_r = \frac{6000 \times 1000}{60\,046} = 99.92 \textit{ amperes.}$$

CHART VIII.—APPLICATION OF TABLES TO LONG TRANSMISSION LINES

(EFFECT OF DISTRIBUTED CAPACITANCE TAKEN INTO ACCOUNT) OVERHEAD BARE CONDUCTORS

Starting with the kv-a., voltage and power-factor at the receiving end known.

QUICK ESTIMATING TABLES XII TO XXI INC.

From the quick estimating table corresponding to the voltage to be delivered, determine the size of the conductors corresponding to the permissible transmission loss.

CORONA LIMITATION—TABLE XXII

If the transmission is at 30 000 volts, or higher, this table should be consulted to avoid the employment of conductors having diameters so small as to result in excessive corona loss.

RESISTANCE—TABLE II

From this table obtain the resistance per unit length of single conductor corresponding to the maximum operating temperature—calculate the total resistance for one conductor of the circuit—if the conductor is large (250 000 circ. mils or more) the increase in resistance due to skin effect should be added.

REACTANCE—TABLES IV AND V

From one of these tables obtain the reactance per unit length of single conductor. Calculate the total reactance for one conductor of the circuit. If the reactance is excessive (20 to 30 percent reactance volts will in many cases be considered excessive) consult Table VI or VII. Having decided upon the maximum permissible reactance the corresponding resistance may be found by dividing this reactance by the ratio value in Table VI or VII. When the reactance is excessive, it may be reduced by installing two or more circuits and connecting them in parallel, or by the employment of three conductor cables. Using larger conductors will not materially reduce the reactance. The substitution of a higher transmission voltage, with its correspondingly less current, will also result in less reactance.

CAPACITANCE SUSCEPTANCE—TABLES IX AND X

From one of these tables obtain the capacitance susceptance to neutral, per unit length of single conductor. Calculate the total susceptance for one conductor of the circuit to neutral.

GRAPHICAL SOLUTION

From the Wilkinson charts obtain the auxiliary constants. Applying these auxiliary constants to the load conditions of the problems, make a complete graphical solution as explained in the text. Vector diagrams of the voltage and the current at both ends of the circuit are then constructed, from which the complete performance can be readily obtained graphically.

MATHEMATICAL SOLUTION

As a precaution against errors in those cases where accuracy is essential, the result obtained graphically should be checked by the convergent series or the hyperbolic method.

From tables the following linear constants per mile are determined.—

r = 0.35 *ohm (Table No. II)*
x = 0.83 *ohm (Table No. V by interpolation)*
b = 5.21 *microhms (Table No. X by interpolation)*
g = *(in this case taken as zero)*

therefore,

$rb = 0.35 \times 5.21 = 1.82$

and,

$rb^2 = 0.35 \times 5.21^2 = 9.50$

The auxiliary constants of the above circuits are now taken directly from the Wilkinson Charts. This problem is stated on the Wilkinson chart. Following the directions printed on the charts, we obtain for this circuit the following values for the auxiliary constants.

$a_1 = 0.81 \quad b_1 = 91.7 \quad c_1 = 0.00004$
$a_2 = 0.077 \quad b_2 = 235 \quad c_2 = 0.00146$

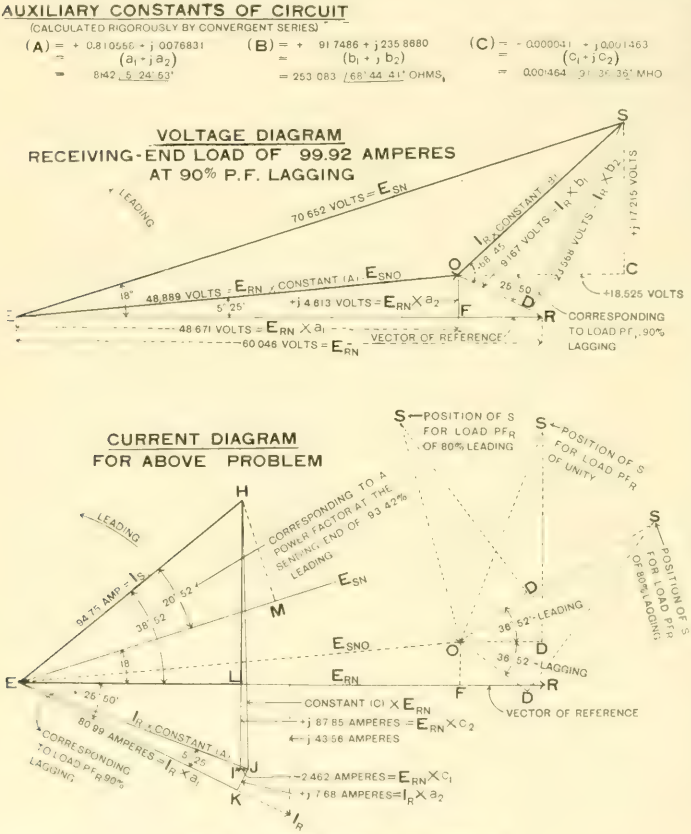

AUXILIARY CONSTANTS OF CIRCUIT
(CALCULATED RIGOROUSLY BY CONVERGENT SERIES)
(A) = + 0.810558 + j 0.076831
= (a₁ + j a₂)
= 8142 /5 24′ 53′
(B) = + 91 7486 + j 235 8680
= (b₁ + j b₂)
= 253 083 /68′ 44 41′ OHMS
(C) = - 0.000041 + j 0.001463
= (c₁ + j c₂)
= 0.001464 /91 36 36′ MHO
VOLTAGE DIAGRAM
RECEIVING-END LOAD OF 99.92 AMPERES
AT 90% P.F. LAGGING
LEADING
70 652 VOLTS = E_SN
S
Iʀ × CONSTANT (B)
9167 VOLTS = Iʀ × b₁
23 568 VOLTS = Iʀ × b₂
+j 17 215 VOLTS
68 45
O
C
+18.525 VOLTS
25 50
D
18°
48,889 VOLTS = E_RN × CONSTANT (A) = E_SNO
5° 25′
+j 4 613 VOLTS = E_RN × a₂
F
R
CORRESPONDING TO LOAD PF 90% LAGGING
E
48 671 VOLTS = E_RN × a₁
60 046 VOLTS = E_RN
VECTOR OF REFERENCE
CURRENT DIAGRAM
FOR ABOVE PROBLEM
S ← POSITION OF S FOR LOAD PF_R OF 80% LEADING
S ← POSITION OF S FOR LOAD PF_R OF UNITY
S ← POSITION OF S FOR LOAD PF_R OF 80% LAGGING
H
LEADING
CORRESPONDING TO A POWER FACTOR AT THE SENDING END OF 93 42% LEADING
94 75 AMP = I_S
20° 52
38° 52
M
E_SN
D
36° 52′ LEADING
E_SNO
O
D
36 52 LAGGING
18
E
L
E_RN
F
D
R
VECTOR OF REFERENCE
25′ 50′
80 99 AMPERES = Iʀ × a₁
Iʀ × CONSTANT (A)
5 25
CORRESPONDING TO LOAD PF_R 90% LAGGING
CONSTANT (C) × E_RN
+j 87 85 AMPERES = E_RN × c₂
j 43 56 AMPERES
I
J
K
−2 462 AMPERES = E_RN × c₁
+j 7 68 AMPERES = Iʀ × a₂
Iʀ

FIG. 27—GRAPHIC SOLUTION OF PROBLEM X

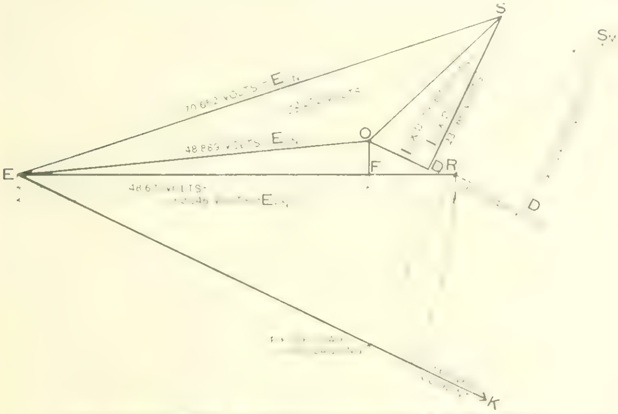
From this point on, the solution is made graphically as indicated in Fig. 27. It should be noted here that the auxiliary constants obtained from the Wilkinson Charts are practically the same as those stated at the top of Fig. 27, which values were calculated rigorously by convergent series. We will employ the rigorous values in plotting the diagram so that the values on the diagram will agree with the values of voltage and current calculated rigorously which will appear in a later section. The *j* terms preceding some of the numerical values in Fig. 27 apply to the mathematical treatment, and have no significance in connection with the graphical solution.

VOLTAGE DIAGRAM

The vector *ER*, representing the constant voltage at the receiving-end (for all loads) is first laid off to some convenient scale. Along this vector, starting from *E*, lay off a distance equal to the receiving-end voltage multiplied by the constant a_1 (60 046 × 0.810558 = 48.671 volts). This is *EF* of Fig. 27. From *F* lay off vertically (to the same scale) the line *FO* equal to the receiving-end voltage multiplied by the constant a_2 (60 046 × 0.076831 = 4613 volts). Connect the points *O* and *E* by a line. This line *EO* represents the voltage at the sending-end at zero load. This voltage vector may, if desired, be located by polar co-ordinates in place of rectangular co-ordinates. If it is desired to work with polar co-ordinates lay off the line *EO* at an angle of 5° 25′ in the forward direction from the receiving-end voltage vector ER. (For the graphical solution it is not necessary to take account of seconds in angles) The length of the vector *EO* will be found by multiplying the constant *A* by the receiving-end voltage (0.8142 × 60 044 = 48 889 volts).

Having located the point *O*, the impedance triangle is built upon it in the following manner. Since the power-factor of the load is 90 percent lagging, determine from a table of cosines what the angle is whose cosine is 0.9. This is found (from Table K) to be 25 degrees, 50 minutes. Lay off the line *OD* at an angle with the vector of reference *ER* of 25° 50′ in the lagging direction. The length of *OD* will be determined by multiplying the current in amperes per conductor by the auxiliary constant b_1 (99.92 × 91.7486 = 9167 volts). This represents the resistance drop per conductor. From the point *D* thus found draw a line *DS* at right angles with *OD*. This line *DS* represents the reactance volts per conductor; its length is found by multiplying the current in amperes per conductor by the auxiliary constant b_2 (99.92 × 235.868 = 23 568 volts). Connect the point *S* with *E*, the length of which represents the voltage (70 652 volts) at the sending-end for the load conditions assumed. The vector *OS* could be laid off by the use of polar ordinates as follows. The polar co-ordinate *OS* is stated as $B = 253.08 \angle 68° 44' 41''$ per ampere at the receiving-end. 68° 45' — 25° 50' = 42° 55' the angle *COS*. The vector *OS* is therefore laid off at an angle of 42° 55' with the vector of reference *ER* or *OC*. The length of the vector *OS* is 253.08 × 99.92 = 25 288 volts. The triangle *OCS* indicated by broken lines is not required for the graphical solution but is calculated in the case of one form of mathematical solution which will follow.

Had the power-factor of the receiving-end load been unity in place of 90 percent lagging, the impedance triangle would have been plotted vertically, that is *OD* would have been drawn parallel with *ER*. In the bottom diagram (representing the graphical solution for current) the position of the impedance diagram is indicated by broken lines corresponding to loads of three different power-factors.



[illegible] The full line diagram takes into account the effect of distributed capacitance. The dotted line diagram (impedance method) neglects the effect of capacitance.

CURRENT DIAGRAM

Lay off the vector *ER* representing the direction of the receiving-end voltage. Since the power-factor of the current at the receiving-end is 90 percent lagging, lay off the line *EK* at an angle of 25° 50' from the vector of reference *ER* and in the lagging direction. To some suitable scale for the current values, measure off *EK* equal to the current at the receiving-end multiplied by the constant a_1 (99.92 × 0.810558 = 80.99 amperes). From the point *K* thus located lay off *KJ* at right angles to *EK* and equal in length to the receiving end current multiplied by constant a_2 (99.92 × 0.076831 = 7.68). This fixes the point *J* upon which the charging current diagram will be built. The point *J* may also be located by the use of polar co-ordinates if desired. Thus *EJ* = 25° 50' — 5° 25' = 20° 25' in a lagging direction from the vector of reference *ER*. The length of *EJ* = 99.92 × 0.8142 = 81.35 amperes.

Now draw the line *IJ* parallel to the vector of reference *ER*. The length of *IJ* is found by multiplying the receiving-end voltage by the constant c_1 (60 046 × 0.000041 = 2.462 amperes). Since c_1 is a negative value the line *JI* turns to the left, the negative direction. From the point *I* thus located draw the vertical line *IR* equal to the receiving-end voltage multiplied by the constant c_2 (60 046 × 0.001463 = 87.85 amperes). This locates the point *H*, which is now connected by a line with *E*. The vector *EH* represents the sending-end current = 94.75 amperes.

The vector representing the sending-end voltage having been located in the voltage diagrams at an angle of 18 degrees in the leading direction, may be plotted in the current diagram. The angle between the current and the voltage at the sending-end may be measured and will be found to be 25° 52' for this problem, corresponding to a power-factor of 93.42 percent. Since the current vector leads the voltage vector the power-factor at the sending-end is leading.

It has been shown above how to determine graphically the voltage, current, phase angle and consequently the power-factor at the sending-end of the circuit. These values thus determine the true power input at the sending-end. This true power may also be determined graphically as follows.

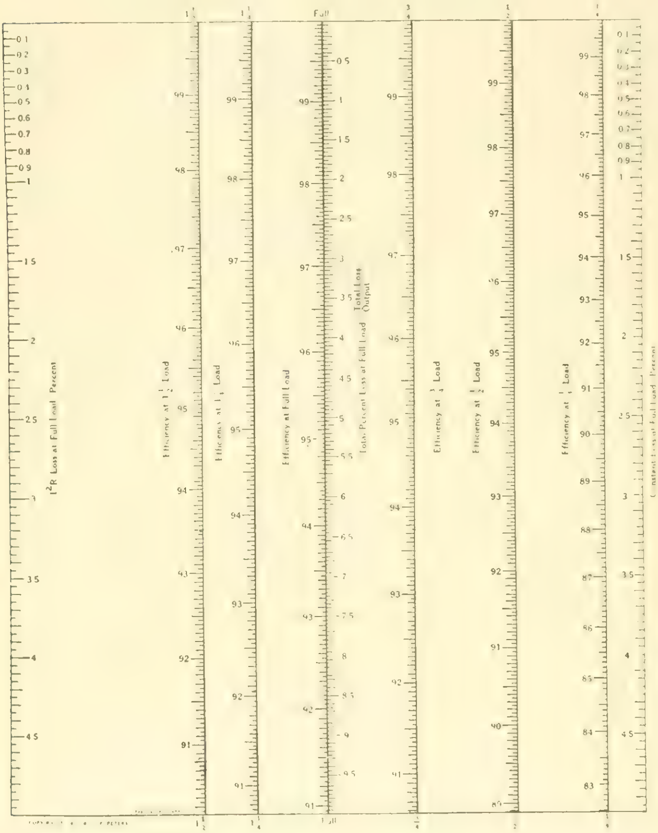
The component of the current at the sending-end which is in phase with the voltage at the sending-end may be scaled off on the current diagram in Fig. 27 as follows. On the diagram the vector *EH* represents the direction and value of the current at the sending-end and the vector E_{sn} the direction of the voltage at the sending-end. At right angle to the vector E_{sn} draw the line *HM* passing through the point *H* (the end of the current vector). To the same scale that *EH* is drawn measure off along the vector E_{sn} the distance from *E* to *M*. This will be the amperes in phase with the voltage at the sending-end. This value multiplied by the voltage at the sending-end, will give the true power at the sending-end.

COMPARATIVE GRAPHICAL SOLUTIONS

Fig. [illegible] shows the graphical solutions for problem *X*. The full line diagram is correct, taking into account the effect of the distributed capacitance. The broken line diagram (the Mershon chart for short lines) does not take into account any capacitance effect. Of course the Mershon chart would not be employed in the solution of long lines, such as given in problem *X*. It is shown here simply to illustrate wherein these two graphical methods differ. The following remarks regarding the Mershon chart will apply equally to any of the other impedance methods, since they take no account of capacitance effect.

The Mershon chart is built upon the receiving-end current as a vector of reference, whereas the full line chart is built up from the receiving-end voltage as a vector of reference. The impedance triangle in the full line chart is built upon the vector representing the zero load voltage at the sending-end, whereas the broken line impedance triangle is built upon the vector representing the voltage at the receiving-end. Herein lies the principle source of error in the application of the Mershon chart to circuits of considerable capacitance. The correct position for the impedance triangle is on the end of the vector representing the sending-end voltage at zero load.

CHART IX—PETER'S EFFICIENCY CHART



To obtain efficiency at any given load, lay a straight edge across the given I^2R and constant loss values and read the efficiencies at the required loads on the corresponding scales. The total percent loss at full load may also be obtained simultaneously.

To obtain the variable and constant components of the loss and the corresponding total percent loss at full load, when efficiency values corresponding to any two loads are given, place a straight edge across the two given points and read the required percent losses on their respective scales. Likewise, if the efficiency corresponding to a given load is known and the constant loss, for example, is known, the variable loss corresponding to the given load may be read from the I^2R scale, and the total percent loss from its scale.

The impedance triangle is smaller in the full diagram than in the Mershon diagram. Herein lies another source of error in the application of the Mershon chart to circuits of considerable capacitance. The full line impedance triangle takes into account the distributed effect, or change in current along the circuit, whereas the Mershon chart is based upon the current being of the same value throughout the length of the circuit.

The actual sending-end voltage is 70 652, as indicated on the full line chart, whereas by the broken line or Mershon chart method it would be incorrectly given as 82 252 volts.

EFFECT OF TRANSFORMERS

In the foregoing discussions no account has been taken of the voltage drop through transformers. Transmission circuits usually have lowering transformers connected between them and the receiving-end load and usually there are also transformers in the sending-end of the transmission circuit.

The inductance and capacitance of a transformer are not distributed in the same manner as those of the transmission circuit to which the transformer may be connected. It is difficult to take into exact account the effect of the transformers, but for practical purposes of power transmission circuits it will usually be sufficient to ignore the effect of the comparatively small capacitance of the transformer windings, but to take account of the reactance of the transformers in the following manner.

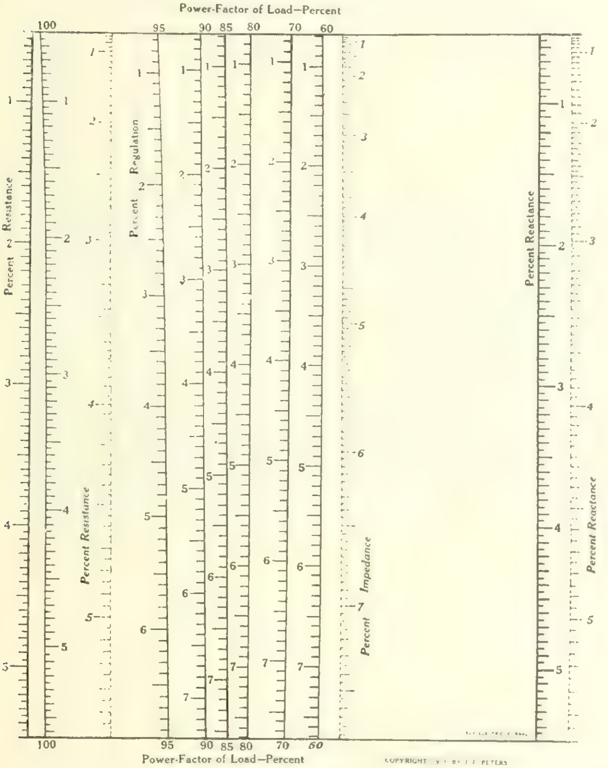
As an illustration, assume that problem *X* contains a bank of transformers (or one three-phase transformer) of 18 000 kv-a total capacity at each end of the circuit, and that it is desired to take into account the effect of these transformers upon the voltage regulation between the generator bus and the receiving-end load. The raising and lowering transformers will be considered as a part of the transmission circuit, and their resistance and their reactance added to that of the transmission conductors. The calculation will be made in terms of the high-tension circuit. If results are desired in terms of the low voltage side of the transformers, they may be obtained from the ratio of transformation. The connection of the transformers is immaterial, as the results will be the same whether star or delta connection is assumed.

Table *M* indicates approximately the variation in the values of the resistance and the reactance volts for 25 and 60 cycle transformers corresponding to units of various capacities. Since the performance of transformers, as applied to specific cases, may vary greatly from these tabular values, it will be desirable in each case, where the transformers are included in the calculations, to obtain the exact performance of the transformers. In order to illustrate the application of the Peter's efficiency chart, it will be assumed that in this case only the efficiency and the regulation of the transformers are known. We will assume also that the transformers will be 18 000 kv-a, three-phase, and that one will be installed at each end of the circuit. Required to find the resistance and the reactance (in ohms) per transformer to neutral. The assumed performance is as follows:—

Efficiency at full load = 98.28 *percent.*
Efficiency at one-fourth load = 96.98 *percent.*
Regulation at 100 *percent power-factor* = 1.15 *percent.*
Regulation at 80 *percent power-factor* = 3.74 *percent.*

By laying a straight edge across the two known efficiency points on Chart IX, the iron and copper losses expressed in percent of full load kv-a of 0.72 percent and 1.05 percent respectively may be read directly from the chart.

CHART X—PETER'S REGULATION CHART



To obtain the regulation for a load of any power-factor, lay a straight edge across the given percent resistance and reactance values, and read the regulation at various power-factors of load on the respective scales.

To obtain the resistance and reactive components when the regulations corresponding to two power-factors are given, place a straight edge across the given points and read the required components on their respective scales. Values for power-factors between those for which scales are given can be closely approximated by interpolation.

The broken line scales are primarily for determining, by means of a straight edge, the reactance when the impedance drop and resistance drop are known. Obviously, with any two of these three factors given, the third can be obtained directly from the broken line scales.

The exact values for the iron and copper loss may, if desired, be calculated by the following simple algebraic procedure. At full load the input is,—

$$\frac{18\,000\,000}{0.9828} = 18\,315\,020 \textit{ watts}$$

so that the total loss at full load is 315 020 watts.

At one fourth load the input is,—

$$\frac{4\,500\,000}{0.9698} = 4\,640\,130 \textit{ watts}$$

so that the total loss is 140 130 watts.

Then let x = the iron loss at all loads
and y = the copper loss at full load
then $x + y = 315\,020$ watts

and $x + \frac{y}{16} = 140\,130$ watts

(the copper loss varies approximately as the square of the load)

so that $16x + y = 2\,242\,080$
and since $x + y = 315\,020$
$15x = 1\,927\,060$
so that $x = 128\,470$ watts or 0.71 percent
and $y = 186\,550$ watts or 1.04 percent

which check closely with the values as previously read from Chart IX.

Assuming a voltage to neutral for these transformers of 60 046 volts and a current of 99.92 amperes per conductor, the copper loss of 1.04 percent will result in an IR voltage drop of 60 046 × 0.0104 = 624 volts to neutral. The ohms resistance will therefore be

$$\frac{624}{99.92} = 6.25 \text{ ohms to neutral for each}$$

transformer. Since the resistance of each line conductor is 105 ohms the resistance per conductor including an equivalent value to correspond to the resistance in the high and low tension windings of two transformers will be,—

$$R = 105 + 6.25 + 6.25 = 117.5 \text{ ohms}$$

The percent reactance volts of a transformer having 3.74 percent regulation at 80 percent lagging power-factor and 1.04 percent resistance volts may be read directly from Peter's Regulation Chart (Chart X) by laying a straight edge along the points corresponding to 1.04 percent resistance and 3.74 on the

80 percent power-factor line. The intersection of the straight edge with the last solid line at the right will give the percent reactance, = 4.85 percent.

The percent reactance volts can also be read directly from the Mershon Chart. To do this, follow upward the vertical line in the Mershon Chart corresponding to 80 percent power-factor until it intersects the first arc. From this point of intersection follow the horizontal line to the right a distance corresponding to 1.04 percent resistance volts. From the point thus obtained follow the vertical line until the arc representing 3.74 percent voltage drops is reached. The length of this vertical line will be the percentage reactance volts of the transformer, in this case 4.8 percent. Of course the reactance may, if desired be calculated by following the general construction traced out as above described upon the Mershon chart, but the chart will give sufficiently accurate values for practical purposes.

TABLE M—APPROXIMATION OF RESISTANCE AND REACTANCE VOLTS FOR TRANSFORMERS OF VARIOUS CAPACITIES

Transformer Capacity in Kv-a	Voltage Drop in Percent			
	Resistance		Reactance	
	25 cycles	60 cycles	25 cycles	60 cycles
[illegible]	2.15	[illegible]	4.0	5.6
500	[illegible]	[illegible]	4.1	6.0
[illegible]	1.2	1.1	4.2	6.3
1000	[illegible]	[illegible]	6.0	6.5
[illegible]	[illegible]	0.9	6.2	7.0
[illegible]	1.3	0.8	6.4	7.0
3000	1.2	[illegible]	6.8	7.0
5000	1.1	0.65	7.2	7.0
7500	[illegible]	0.6	7.8	8.0
[illegible]	1.0	[illegible]	8.0	8.0
[illegible]	0.95	[illegible]	8.0	8.5
[illegible]	0.9	0.5	8.0	9.0

The volts necessary to overcome the reactance of the windings of one of these transformers is therefore found to be 60 046 × 0.048 = 2882 volts to neutral. The ohms reactance will therefore be $\frac{2882}{99.92} = 28.84$ ohms to neutral for each transformer. Since the reactance of each line conductor is 249 ohms, the reactance per conductor, including an equivalent value to correspond to the reactance in the high and low tension windings of two transformers will be,—

$$X + X_t = 249 + 28.84 + 28.84 = 306.68 \textit{ ohms.}$$

The impedance of one conductor of the circuit of problem X including the raising and lowering transformers will be,—

[illegible]

With the assumed values for the impedance, the performance of the combined circuit may be calculated as though there were no transformers in the circuit.

VOLTAGE AND CURRENT AT INTERMEDIATE POINTS ALONG THE CIRCUIT

Thus far we have considered the electrical condition at the two ends of a transmission circuit only. Occasionally it may be desired to determine the voltage or the current at a point, or at various points along the circuit. In Fig. 21, graphs of the voltage and of the current are shown for points between the terminals of a circuit corresponding to the condition of zero load, and also of rated load. The graphs were plotted by determining graphically the voltage and the current for points at 50 mile intervals along this 300 mile circuit, as follows:—

To determine the conditions 250 miles from the sending-end, (50 miles from the receiving-end) the three auxiliary constants were obtained from the Wilkinson charts corresponding to a circuit 50 miles long. In other words, it was assumed that the circuit was only 50 miles long. By multiplying these auxiliary constants by the known voltage and current at the receiving-end of the circuit, voltage and current diagrams were constructed as in Fig. 27 and on these, the corresponding values of voltage and current at the sending-end of the 50 mile section were scaled off. This gives the conditions, for the load assumed, at a point 250 miles from the sending-end. In a similar manner the voltage and current at this point, corresponding to zero load at the receiving-end, may be obtained. A similar precedure will determine the electrical conditions for a point 100 miles from the receiving-end (200 miles from the sending-end). The auxiliary constants will this time be read from the charts, corresponding to a 100 mile circuit, but the same receiving-end conditions will be used, as before. The electrical condition for any intermediate points along any smooth line, may thus be readily determined.

Electric Controllers for Mine Hoists

W. C. Goodwin

THE APPLICATION of electricity to the hoisting of coal and metals from mines has developed during the last decade to such an extent that practically all new installations are electrically operated, and many old steam-driven hoists are being replaced by motor drives, with a large increase in efficiency and work done by the hoist. As a result, controllers are needed for increasingly larger power and higher potential alternating-current motors. In many installations, controllers must be capable of reversing the motor frequently, of giving automatic acceleration, speed control, numerous safety features, and be of simple and rugged construction. With the increase in size and voltage of motors for these installations, new primary circuit controllers have been developed which permit frequent closing and interrupting of high potential circuits without undue wear or decrease in reliability, due to the deterioration of such elements as the oil in circuit breakers. Controllers used with small power and low-voltage motors, are of a standard low voltage type, which have been somewhat standardized. But with high-voltage motors, different primary controllers are necessary, such as contactors under oil, or larger and more efficient air-break contactors.

A noteworthy and typical installation of a high-voltage electric motor mine hoist, showing the latest trend of engineering development in hoist and control apparatus, is shown in Fig. 1. This is a slope hoist for one of the largest bituminous coal mines in western Pennsylvania. It is a single track slope and consequently has an unbalanced load. The slope is from four to five thousand feet in length, 95 percent of which has a 6.5 percent grade while the rest of the slope, which is used as a runaway outside of the mine, has a grade of four percent. Coal is hoisted not only from the bottom of this slope, but also from a level about midway. At this level the cars have to be pulled around a curve onto the main track, requiring the maximum torque of the hoist motor.

A novel use has been planned for this hoist for the future. As the cars are hoisted, they are pushed out onto a storage runway, and from there delivered to the tipple by a storage battery locomotive. The coal is then loaded into railroad cars and carried ten miles to a nearby river, which is at a lower level. At this point there is a level entrance into another mine of the same company, which runs back within several miles of the first mine, but at a much lower level. In the future development of these mines it is planned to lower the coal from mine number one to the lower number two mine, instead of lifting it to the surface and transporting it to the river by railroad. This will be done by cutting the present slope through to the second mine and using the present hoisting equipment to lower the coal from the upper to the lower mine whence it will be hauled by mine locomotives to the river entrance, where no hoisting equipment is necessary. The new slope will be between two and three miles long.

The present haulage consists of twenty to twenty-five cars, of 1.75 tons each, loaded with 6.5 tons of coal on the up-grade travel. On lowering, the load consists of a string of empty cars and supplies. The maximum torque is required to bring the load from the midway level around the curve onto the main track.

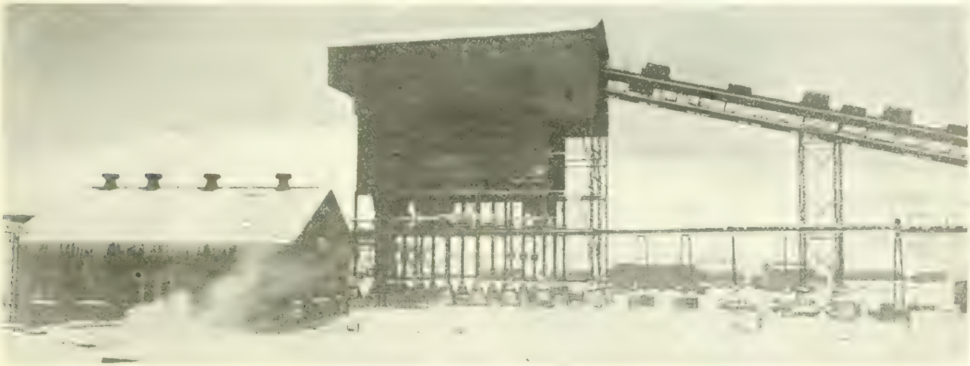


FIG. 1—VIEW OF HOIST HOUSE AND TIPPLE

In the foreground is shown the hoist house which houses the electric hoist and control apparatus. The [illegible] appears in the foreground from the hoist house toward the mine at the right. After the coal wagons are hoisted out of the mine, they are allowed to run back through a switch onto a storage siding. A storage battery locomotive then pushes them to the lower end of the tipple slope, where a continuous slow moving chain, with projections at equal intervals, hoists them to the top, where the coal is dumped. The same chain then lowers the empty wagons down an adjacent slope to the bottom. After leaving the chain, the wagons roll down onto a siding, and are then pushed by the storage battery locomotives back onto the empty siding, where the main hoist cable lowers them into the mine.

This is secured by having a two-speed reduction gear between the motor and the drum; and using the lower speed instead of using a motor with a higher pull-out torque. With the ultimate longer slope, the load will be lowered, and the empties hoisted to the upper mine. With this arrangement an increased number of cars can be hauled, while operating at the higher speed.

The hoist machinery with its driving motor is shown in Fig. 2. The drum, which is a smooth cylinder, nine feet in diameter, is connected to the driving motor through a two speed reduction gear, giving 5 to 1 and 10 to 1 reduction with a 24 pole, 60 cycle motor. The gears are shifted to give the desired speed by an air-operated cylinder and piston controlled from the operator's stand. There are two brakes, one a shoe brake operating on the drum, and the other a band brake acting on a wheel mounted on the shaft of the reduction gear. These brakes are both operated by compressed air cylinders. The motor has a wound secondary and pedestal bearings. Mounted on the operator's platform are the drum master controller, the control handle for the air-operated gear shift, the brake control handle, a maximum torque push button, an emergency switch, a drum controller to allow backing out when running past the track limit switches and a telephone. The action of these latter devices will be explained later. A voltmeter and ammeter are mounted in front of the operator. The voltmeter, which is connected to a magneto driven by the motor, is calibrated to give the speed of the motor in r.p.m. The ammeter indicates the current to the motor.

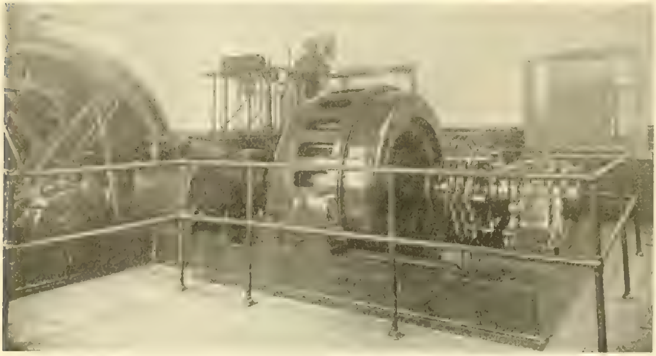


FIG. 2—MAIN HOIST DRUM AND DRIVING MOTOR

CONTROL OPERATION

A general view of the control apparatus is shown in Fig. 3. The primary control consists of an incoming power switchboard of two panels, on which are mounted the oil circuit breaker, the protective relays, the indicating and recording meters, and a primary control board made up of three primary contactors, which are used as forward, reverse and line switches. These contactors, as shown in Fig. 3, are of an entirely new type, suitable for use on alternating-current circuits having a maximum voltage of 6600, and a current carrying capacity of 500 amperes. Each contactor is mounted on a panel which is supported by a heavy, channel-iron framework. The magnet frame, with the operating magnet and armature, is bridged across the two upright channels of the framework. The operating magnet is a large *U* shaped, single-phase magnet, having two operating coils. It is of the type often used on alternating-current, magnet-operated brakes. At each end of the armature shaft is mounted a contact arm, consisting of a long, hollow micarta insulating tube, with the moving contact support fastened at the top. The main current carrying parts are insulated from the frame or ground by the micarta tubes and sufficient insulation is provided for 6600 volts by having the terminals and magnetic blowout panel mounted on porcelain insulators. Each pole is entirely separated from the others by being mounted on individual insulators. The stationary contact, the series blowout coil and the magnetic arc blowout box are mounted on a slate panel which is supported on porcelain insulators. The arc box is new and unique in design. The parts that are exposed to the arc during rupture are built of a special moulded composition. The length of the arc is increased and at the same time confined within the field of the magnetic blowout by the addition of spacers or "arc splitters" in the path of the arc in the box. These arc splitters are also made of moulded composition and there are several of them placed at right angles to the arc path, their locations being shown in Fig. 4. The blowout box is large and rigidly supported by the slate and contact support casting. A removable piece or window is provided, whose removal exposes the contacts and provides room to remove and replace them with new ones. Relays which are operated by the action of the contactor armature tail piece or otherwise are mounted on a slate panel supported by the magnet

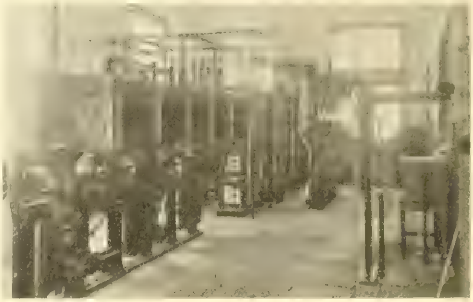


FIG. 3—GENERAL VIEW OF CONTROL ROOM
Showing primary controller, secondary control panel and grid structure.

frame and channel irons. The operation of the contactor is the same as usual on low-voltage magnetic contactors, in that the contacts are closed when the magnet is energized and are opened by a spring and gravity when the magnet becomes deenergized.

The secondary controller is shown in Fig. 5, and consists of a seven-step resistance grid structure and a panel board with magnetic contactors for short-circuiting the resistance, together with the series accelerating relays to give current limit acceleration. The relays are held inoperative by a spring when the switch is open, and released from the action of the spring by the tail piece of the contactor mounted directly above, when the switch closes. However, the relay contacts are still held open by the current in the relay coil, which is in series with one leg of the secondary circuit, until the current has decreased to a predetermined value, at which the contacts close and allow the completion of the circuit to the operating coil of the contactor that short-circuits the next step of secondary resistance.

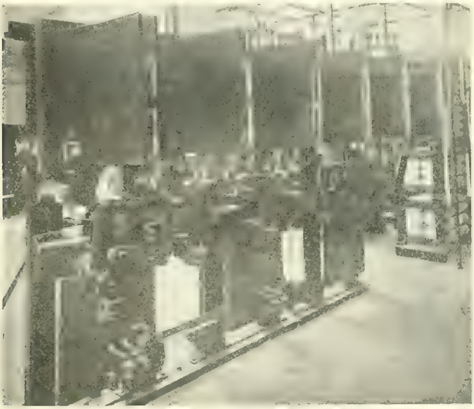


FIG 4—PRIMARY CONTROL CONTACTORS

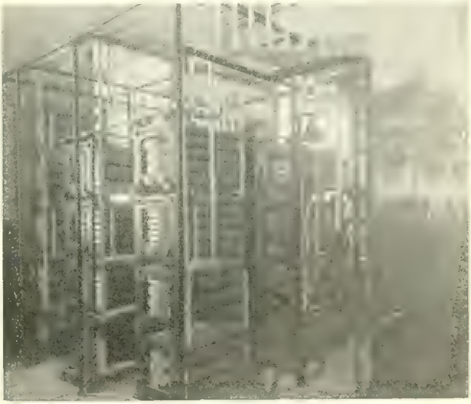


FIG. 5—SECONDARY CONTROL PANEL AND GRID RESISTORS

The secondary contactors are all two pole except the first one, which is single pole. By referring to Fig. 6 it can be seen that the single-pole contactor is the first accelerating switch, and leaves one leg of the resistor open on the first point. This gives small torque and is used for pulling up the slack rope and for starting the load down the slope after a stop at any point.

The speed switch is a control circuit switch which is operated by a ball governor, driven by the drum. The switch opens the control circuit, if the governor speed attains a certain percentage above the high-speed of the motor and hoist. When the hoist is changed to low speed, by changing the gear, the *partial speed switch* is closed automatically. This switch operates the *half-speed solenoid* which in turn sets the speed switch to open at any speed in excess of half-speed. The opening of the speed switch opens the main control circuit and disconnects the controller. In addition there are several auxiliary control switches.

Track limit switches are placed near the upper and lower limits of the track and are opened by the passing of the cars over the track where they are located. The opening of either the upper or lower switch opens the main control circuit and stops the motor.

Over-travel switches are also provided, which are operated by a cam driven by the drum. These perform the same function as the track-limit switches and open the control circuit on an over-travel of a certain distance beyond the track switches.

After either the track limit or the over-travel switches has opened, it is impossible to start the motor and get back out of the limit zone until the opened limit switch has been closed or short-circuited. A drum type, backout switch is, therefore, provided that short-circuits the track and over-travel switches, and starts the motor in the direction opposite to the over-travel, provided the master controller has been returned to the off position. This backout switch is controlled by the operator, and is only needed in the backout position, until the cars have passed back over the limit switches and allowed them to close. The operator has a small emergency safety switch by which he is able to open the control circuit at any time and stop the motor, in case of an emergency.

The brake is operated by gravity and released by compressed air. Thus, with failure of air supply, the brakes are set. A brake magnet is provided, that has to be set and electrically held closed in order to make the brakes operative. With absence or failure of electric power, the brake coil releases its armature and sets the brakes. The armature is hand set, and has a switch that is operated by the magnet armatures, which prevents burning out the coil if the magnet is left in the open position when power is on, as an alternating-current magnet takes a very large current when the armature is open.

The first few points of the secondary controller are designed to give small torque. If the load is too heavy, and the motor stalls, it is possible by using the maximum torque push button to short-circuit several controller steps. This push button is connected to the point which gives a standstill torque closest to the maximum or pull-out torque of the motor.

The general functioning of the controller can be followed from Fig. 6. The master switch, when in the *off* position, closes the control circuit contactor, located in the middle of the secondary control panel. When this switch has been opened by the operation of any of the emergency switches or relays, it can be reclosed only by returning the master controller to the *off* position. The movement of the master switch to the first position closes one of the relays under the primary contactors, which in turn closes two of the three primary contactors, either *line* and *hoist* or *line* and *lower*, depending on the direction of movement of master switch handle. The motor is now connected to the line with all the resistance in circuit, as shown on the scheme of secondary connections. The second step of the master switch allows the closing of the secondary contactor *11* as soon as the current in the accelerating relay under the primary line contactor has decreased to a predetermined value and allowed the closing of its contacts.

The further movement of the master switch handle allows the secondary contactors to short-circuit the secondary resistance in steps, each contactor being held open until current in the accelerating relay of the previous contactor has decreased to its calibrated value. This is continued until the motor secondary is short-circuited, or the motor has attained the speed corresponding to the position of the master controller.

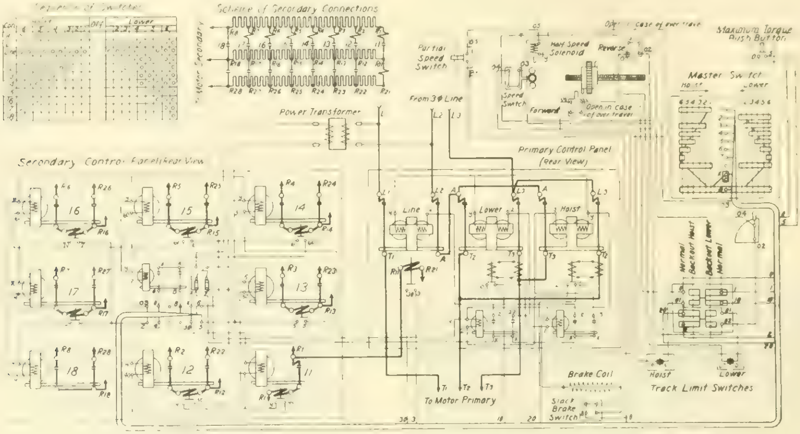


FIG. 6—DIAGRAM OF PRIMARY AND SECONDARY CONNECTIONS

In addition to the control apparatus for the main motor there are in the control room:—*a*—a compressor set for delivering air to a storage tank which is used for braking and gear shifting; *b*—a small automatic control panel for controlling the motor for the compressor, with its pressure gauge, pressure relay, contactor and relays; *c*—a small battery charging panel, which is used for charging a battery used for signaling between the operator and the man that rides the train of cars.

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

To receive prompt attention a self-addressed, stamped envelope should accompany each query. All data necessary for a complete understanding of the problem should be furnished. A personal reply is mailed to each questioner as soon as the necessary information is available; however, as each queston is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply.

[illegible] What is [illegible] average power-factor over a period of one month? Take for example the following conditions. A [illegible] at full load and (assuming they run the full month at this load) they can maintain a power-factor of 99 percent. by running a condenser. Obviously the average is 99 percent. Now if the [illegible] days with a power-factor of 99 percent and for 23 days is practically shut down (their power-factor during the latter period being 80 percent) what is the average power-factor for the whole month. Can the average power-factor be arrived at by taking say half-hourly readings and averaging out? Supposing two intergrating wattmeters are used, connected for determining power-factor, will the result be the same if the difference is taken at the end of the month only, by the two-wattmeter method, as will the result given by taking half-hourly readings of power-factor and averaging out by the number of readings, if (as in the foregoing example) for 23 days the power-factor is 80 percent with a very light load (say 500 kw) and 99 percent for the other seven days in the month with a very heavy load—say 3000 kw?

F.J.R. (ALBERTA)

Our reply would be the same as that

of the farmer who for the first time saw a giraffe "there ain't no such animal". Power-factor is a ratio not a quantity, and averaging the power-factor has no meaning whatsoever. We presume that the question was inspired by a discussion of rates in which there is either a penalty or a discount for power-factor. In this case the only definition which could be used would be one which was arbitrarily agreed upon at the time the contract was drawn up. In case no such definition was agreed upon, the term average power-factor would be meaningless. Adding half-hour power-factor meter readings and dividing by the total number of readings would give you merely an arithmetical number which would have no physical or electrical meaning. Incidentally the reading of a power-factor meter does not necessarily give the power-factor according to the A.I.E.E. definition. The correct definition of power-factor is the ratio of watts to volt-amperes, which will be different from the reading of any commercial power-factor meter, if the load on the phases is unbalanced materially or if the wave shape of the machines departs from a pure sine. Cases are possible where a power-factor meter would indicate close to unity when the true power-factor was in the neighborhood of 0.50. The average power-factor over a period of a month might be considered as the ratio of the total kilowatt-hours as measured by watt-hour meters to the total kilovolt-ampere-hours in the same period of time as measured by ampere-hour meters and volt meters. Power-factor obtained by the ratio of wattmeter readings would be the same as this only if the load is the same in all the phases. Unless the load is balanced, power-factor cannot be obtained by the ratio of wattmeter readings. See article by C. R. Riker in the JOURNAL for Sept. 1912, p. 765. It would not be the same as the arithmetical average of half-hour power-factor readings. The ratio thus obtained would not represent average power-factor; but it would probably come as close to a definition as is possible. Contracts using such terms are manifestly incomplete unless the term is defined as part of the contract.

P.M. AND C.R.R.

1853—DRAINING WATER COOLED TRANSFORMER—Is it advisable to cut off the water supply to oil insulated, water cooled transformers when they are to be kept out of service for some time? R.B.G. (MONT.)

It is always desirable to cut off water supply and drain the cooling coils of an O.I.W.C. transformer when it is to be kept out of service for some time and absolutely necessary if there is any danger of freezing. If the water in a cooling coil freezes up solidly the coil will undoubtedly burst. W.M.M.

1854—ELECTROLYTIC CORROSION — Two years ago I had a number of steam, water and air pipes, also a number of large conduits buried twelve inches under ground under a shop floor which was afterwards filled over with coal cinders. This winter it was necessary to dig down to a water pipe to stop a leak and upon inspection of the pipe it was found that it was in a very bad condition, indeed, in far worse shape than would possibly be expected from ordinary corrosion. It is my supposition that this deterioration has been caused by chemical action produced by drainage of water through the cinders on top of the ground, but a party has advanced the theory that it was caused by electrical action and, while I am unable to conceive such a possibility, I recall reading something regarding such action. I would be very glad to have you advise me if such electrical action is possible; also the cause and remedy.

L.M.G. (OHIO)

The eating away of pipes in the ground can be caused either by the passage of electric current from external sources, in which case it is designated "electrolytic corrosion", or by what is known as "self corrosion" due either to electrolytic action from currents caused by cell action, or to chemicals in contact with the pipe. If the corrosion is due to current from external sources in the pipes it can be reduced by making connections to the pipes to cause them to be negative to the surrounding earth. In the case of pipes subject to current flow from street railways, this is often taken care of by bonding between the track and the pipe at points where the track is negative to the pipes. Another scheme used is the connection of a negative feeder to the pipes, so as to drain them. If there is no electric current flow in the pipes from external sources, the case comes under the general head of "self corrosion". This is affected by the moisture contained in the soil, by chemicals, and other causes. The matter is covered by Technologic Paper No. 25 of the Bureau of Standards, under the subject "Electrolytic Corrosion of Iron in Soils", by Burton McCullom and K. H. Logan. Self corrosion is especially liable to occur in pipes buried in ashes as there seems to be an acid in certain coal ashes which will eat pipes away in a few months. One large concern who were much troubled in this way solved the difficulty by hauling clay and filling in around the pipes with the clay.

A.W.C.

1855—PARALLEL OPERATION—Would any serious difficulty be encountered in paralleling a 150 kw, 250 volt, direct-current generator that is direct connected to a three-phase, 1200 r.p.m., 2300 volt synchronous motor with a 125 kw, 250 volt generator, direct connected to a 185 hp. steam engine, speed 250? I am aware that it will be necessary to have the series coils equally balanced as to resistance on each machine. However, it occurred to me that perhaps the wide difference in the speed might seriously affect the regulation of one or the other to an extent that they would not divide the load properly. The load will fluctuate considerably, being used for coal mine service. B.L.C. (IND.)

No difficulty should be expected in paralleling these units. Regardless of what adjustments are made, it probably will be found that the high-speed machine will take the load swings. To obtain proper load division with slow variations in load, the customary adjustments of compounding the drop are advisable. The first adjustment is to obtain, by the use of the proper series field shunts, the same change in voltage from no load to full load when the generators are operating independently. The second requirement, as suggested above, is that the *IR* drops over the series field circuits be the same, with the generators operating independently. This may involve the use of an additional resistance in one of the series field circuits. A very essential condition is to have the resistance in equalizer cables and connections negligible in comparison with the series field resistance.

F.L.M.

1856— ALTERNATOR EXCITATION—Would a 25 kw, three-phase, 60 cycle, 220 volt, generator of the rotary converter type, that is one with a direct-current armature connected to three slip rings, be as good as a generator with an exciter?

A.H.V. (ILL.)

We assume that the "rotary converter type" alternator is properly designed for alternator service. This may not be the case if it were designed only for rotary converter operation. This self-excited alternator would still be inferior to a separately-excited alternator in that changes in load current and power-factor would affect the exciting voltage and cause greater changes in alternating voltage than in the separately excited alternator. F.D.N.

1857—COMMUTATION TROUBLE — I have the care of a 200 kw, 667 amperes, 250 volts,—300 volts full load, 990 r.p.m. eight pole, compound-wound Ridgeway generator. It will run along without any spark at no load but if a load of 300 or 400 amperes is suddenly thrown on, the brushes make a snapping sound and little fine sparks are visible. When the circuit breaker flies out occasionally it will flash from one brushholder to another, just on one side of machine. Now, if this machine compounds too much and when the breaker trips at 750 amperes, does it cause a high induced current, or if the stator was a little closer on one side would that cause it? The rocker ring is set at the marks made in the factory. One brushholder does not line up with the commutator, it being out 1/8 of an inch in the space of 4 brushes, there being four brushes to one set. The brushes measure one by two inches and span three segments.

R.K. (PA.)

The snapping scintillating sparks at the brushes, when half load is thrown on indicate an unbalanced condition of armature and compensating current. As the compensating winding is in series with the armature winding and the direction of current in the conductors of the compensating winding is opposite to that of the armature conductors immediately adjacent to them, any change in armature strength should be accompanied by the same change in the compensating winding, otherwise there are some unusual conditions which disturb this balance. Ridgway machines may sometimes be over-compensated, and a shunt provided across the compensating winding to by-pass some of the current which would go to the compensating winding, it being much easier to shunt a portion of the current than to modify the compensating winding. Furthermore, machines of the same designs vary, no two being exactly alike. The shunt causes a closed circuit around the machine and makes the action of the compensating winding slightly sluggish, so that if there is a tendency to spark, due to sudden fluctuations in load, the action will be exaggerated.

If the generator sparks at some of the brushes, it is safe to assume the brushes are improperly spaced, the brush tensions too weak, some of the compensating winding short-circuited, or the wrong grade of brushes used. To set the brushes properly, put a strip of paper about two or three inches wide around the commutator under the brushes, marking the ends where they overlap, and the front edges of the brushes where they bear on the paper, the brushholders being clamped on the brushholder studs as in operating condition. Mark the position of the brushes as *1*, *2*, etc. (Numbers are stamped on the brushholder studs.) By the aid of dividers, laying the paper on a smooth surface, the total distance around the commutator can be stepped off in equal parts, and with this distance set on the dividers the variations of brushes from standard may be determined. There is a certain amount of clearance between the brushholder stud support and the yoke ring and steadying ring (at outer end), which allows of adjustment. Care should be taken to see that the brushes are exactly vertical and parallel with the commutator bars. The brushholders are lined up with a jig at the factory, but they may have moved through accident, loosening of nuts, taking down of yoke ring or a variation in the air-gap.

After the brushes are adjusted, assuming that the air-gap has been found O. K. or made so, the compensating coils should be checked for short-circuits. With full load on the generator, take the drop across each coil with a low reading voltmeter. With the same current flowing, these IR drops should be the same; if they are not, there may be a partial short-circuit in the coil or coils that read low. The re-adjusting of the brushholders may have disturbed the setting of the brushes relative to the yoke ring, so that a new position of the yoke ring in relation to the holding bracket may be necessary, differing slightly from that indicated on the ring at the factory.

With full load on the generator, the yoke ring may be moved a small amount either way until perfect commutation is reached. This is assuming that the shunt provided on the compensating winding has not been disturbed, and has not burned out, and the commutator and brushes are in good condition, with no short or open circuits in the armature. To get the proper adjustment of shunt and brush setting, the voltage between the brushholder and the commutator bars should be taken, preferably with a double reading voltmeter, say 5-0-5. At no load and full voltage the voltage between positive brushholder and points on commutator one-half inch on either side of the brush should read approximately the same, in a negative direction, otherwise the yoke ring should be moved to obtain this before determining other points. At full load, at points one-fourth inch on either side of the brush face, the voltage should be approximately zero, as shown in Fig. (a). With clockwise rotation, viewing the generator from the commutator end, the voltage readings taken at the edge of the brush first touched by the commutator bar, ¼, ½, ¾ way in, and at the edge where the bar leaves the brush, should be approximately 1, 0.95, 0.85, 0.75 and 0.7 volts respectively. This is slightly overcompensated, and about ideal for this type of machine. If the line is too steep, more shunt would be required and vice versa. If the higher voltage is at the forward side, it indicates under-compensation and a portion of the shunt should be removed. Shunts are composed of 0.1 or 0.2 ohm tubes (of 100 watts continuous capacity) in parallel to carry the desired current.

Circuit Breaker—If the generator is operating in parallel with another machine with equalizer connections, and only one circuit breaker, and that on the side of the generator not having the compensating winding, opening the circuit breaker is liable to cause flashing, as the compensating winding is still energized through the equalizer connection to the other generator, while the current value in the armature is practically zero; thus making a very strong over-compensation. A double circuit breaker is preferable so that the armature and compensating winding can be opened simultaneously.

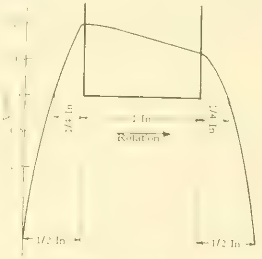


Fig. 1857(a)

Another point to be considered in this connection when generators are operating in parallel, is cutting out a Ridgeway generator. This should be done by tripping the circuit-breaker without lowering the voltage by the use of the field rheostat, as is sometimes done on compound generators. The compensating winding forming a parallel circuit with the series winding of the other machine will have current in its coils in excess of the armature current if the voltage is lowered, which will cause disastrous sparking.

These instructions are general, and should the generator need much adjustment, the manufacturer should be consulted, especially if it is a case of compensation adjustment

C.M.C.

1858—Electric Heating—We have a steel drum sixteen feet long by four feet in diameter into which we dump at one end refuse to be dried. We are now operating this with an oil furnace, which is connected to the smoke stack through this revolving drum. The heat passing through this drum thereby dries the contents. The drum is slightly lower at one end which allows the dried contents gradually to gravitate out of the drum. We are figuring on applying the heat to this drum electrically, having available 50 cycle current of any voltage desired. The temperature inside this drum will have to be about 1000 degrees F. on the basis of outside temperature of 60 degrees F. This will take care of the moisture within the drum. What we want to know is what you would suggest in the way of heating elements to be applied. T.J.B. (NEB.)

It would be quite easy to apply electric heat to the dryer, such as outlined above, 1000 degree heat is well within the temperature limits of a cheap grade of resistance wire, such as Advance, or even Monel-metal and the resistance for the desired amount of heat should be made up and set immediately adjacent to the lower end of the drum and encased in an asbestos insulated, metal housing. There should then be arranged a motor blower, to drive an air blast through the rheostat to transport the heated and dried air into the drum for drying the material which it is arranged to treat. From the data given it is impossible to determine the amount of heat required, and consequently, the cost of power, as you do not give the weight of material being handled and the percentage of moisture being evaporated. W.E.M.

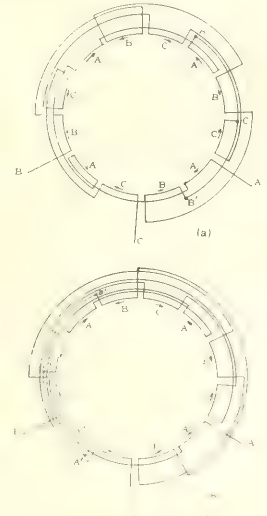
1859—Synchronous Motor For Power-Factor Correction—(a) What are the main differences in design between a synchronous motor intended for mechanical work and one arranged to be used as a synchronous condenser? Can any synchronous motor be easily changed from one to the other of these duties and what is necessary to make this change? (b) I have a 350 hp, 50 cycle, 3000 volt, 50 ampere, 103 r.p.m. synchronous motor at present working, but that I can spare to be used as a synchronous condenser. This motor ought to be good for a power-factor correction of from 0.72 to 0.85 lag on an 850 kw circuit. I have tried overexciting it up to 0.70 or even 0.60 leading power-factor while floating idle on the line and still I get but a very slight correction on the composite power-factor of the plant. Why is this? A.O.U. (MEXICO)

(a) A synchronous motor intended for power-factor correction differs from one designed for mechanical work alone in that its field winding must have capacity for carrying a much larger exciting current than is required for the motor which carries mechanical load only. A motor which has been designed for carrying mechanical load at 100 percent power-factor may be used as a condenser without any changes, although its rating as a condenser will not be very high. In order to make the machine take full-load armature current when floating on the line, the field will have to be over-excited to such a degree that the field winding will probably have a prohibitive temperature rise. With the field current at its maximum safe value, the armature will carry something less than full-load current and the machine will act as a condenser of reduced rating. Some motors are designed for 80 percent power-factor, which means that they carry a certain mechanical load and correct power-factor at the same time. Such a machine has a liberal field winding and, when acting as a condenser without mechanical load, it can carry a larger proportion of full-load kv-a than a 100 percent power-factor motor. (b) To correct the power-factor of an 850 kw load from 72 to 85 percent requires about 293 kv-a condenser capacity. The question does not state whether the motor is two-phase or three-phase. If it is two-phase, its full-load kv-a is 300, and if three-phase, it is 260 kv-a based on a full-load current of 50 amperes. In either case, it would require approximately the full load kv-a of the machine as a condenser to correct the power-factor of the system the desired amount. As stated above, if the motor is a normal machine and was designed for 100 percent power-factor operation, it is not probable that the field will stand the increased excitation that will be required. It should be noted that a power-factor of 60 percent or 70 percent on the motor when it is running light does not mean much in the way of power-factor correction. The kw taken by the motor is only enough to supply its losses, which are probably not over 10 percent of full load kw. Then if the machine is over-excited to 60 percent power-factor, the kv-a or armature current is increased to about 17 percent of full load. The ammeter should be watched instead of the power-factor meter, and when it shows full-load current, it will be found that the power-factor of the whole system is improved considerably. The power-factor on the motor itself will then be close to zero percent. Q.G.

1860—Parallel Operation Of Shaft-Driven Alternators—I have been asked to do the electrical work in connection with the installation of a 100 kv-a, 60 cycle, three-phase, 2300 volt alternator. This includes equipment for synchronizing with another alternator of about the same description. These two machines are to be belt driven through friction clutches from a common line shaft, which is in turn driven by a water wheel. I can readily see that parallel operation under these conditions will be unsatisfactory but as I can find no authority on the matter, I would be pleased to receive information as to just what can be expected under these conditions.
R.S.H. (NEB.)

It is obvious that if the two alternators were mounted rigidly on a common shaft in the proper angular position with respect to each other, and were driven by one prime mover, they should operate satisfactorily in parallel, providing the external voltage characteristics were similar and the field currents were properly adjusted. Similarly, if the two alternators were driven as indicated in the above question, and neither belts nor clutches had any slippage, parallel operation should be satisfactory after once being properly adjusted. Moreover, if the belts and clutches of both machines had the same degree of slippage, correct load division should be obtained, so long as no external force produced an angular displacement between the rotors of the two machines. If, for some unknown reason, the rotors of the two alternators should get an angular displacement, with respect to each other, the overloaded machine would tend to shirk its load and drop back in phase, but in so doing would drag the lightly loaded machine back also. Likewise, if the lightly loaded machine tended to speed up, and take more load, it would drag the other machine forward so that in either case the angular displacement would remain constant, unless there was belt or clutch slippage. Since in actual cases there is more or less belt and clutch slippage, the load shirking action of the alternators should gradually diminish any angular displacement between the two rotors. Consequently, it would appear from a purely theoretical consideration that the two alternators mounted and driven as indicated in the above question should operate in parallel, with at least a fair degree of satisfaction, provided the machines were adapted for parallel operation and provision made for adjusting the belt-tension of each machine independently. However, parallel operation would not be as successful as in the case of separately-driven machines, for a longer time is required for the generators to adjust any disturbed angular displacement between them. It is necessary, of course, to have very accurate pulley dimensions in order to obtain the same synchronous speed for the corresponding load conditions on each machine. It must also be recognized that the slippage of the belt will depend on the surface conditions, so that it is probable considerable attention will be required to maintain proper division of load. This method of parallel operation was used almost entirely in the earlier days with quite satisfactory division of the energy load among the different machines, but required frequent adjustment of the tension of the driving belts. C.M.L.

1861—Induction Motor Diagrams—The two conventional diagrams show different ways of making the end connections on a three-phase four-pole series star stator winding. Either scheme seems to be correct as far as the operation of the motor is concerned. Fig. (a) gives a more symmetrical arrangement of the connections on the coils. Has either scheme any advantages over the other, or are there any objections to either method of making the connections.
J.R.L. (TENN.)



Figs. 1861(a) and (b)

(a) If the windings are to be connected in series as shown, there is no electrical or magnetic difference between them and the choice may be made solely on which one works out best mechanically when connecting. (b) If the windings are to be connected in parallel and there is any reason why the reactance of the two branches in parallel must be exactly the same, or if it is a "T" connection for three-phase, the diagram in Fig. (b) is preferable, since all the north poles are in one branch and all the south poles in another branch and any change whatever in the magnetic conditions such as unequal air gap will affect both branches similarly. (c) If it is desired to parallel the windings and avoid unbalanced magnetic pull or the tendency to it, which creates mechanical vibration and noise, then the diagram in Fig. (a) is preferred, as one mechanical half of the machine can be balanced against the other half. In practice both arrangements are used interchangeably and on a symmetrical winding no difference is detected. A.M.D.

1862—Multispeed Alternating Current Motor—Can a three-phase alternating-current motor be wound so as to obtain several different speeds from only one set of windings, by changing the connections between the coils, and making use of all the windings for each different speed?
R.J.L. (CAL.)

The two-speed induction motor of the usual type, obtains two running speeds by changing the coil connections. This arrangement utilizes the complete winding at both speeds without introducing complicated connections. The scheme depends upon a special winding with coils having a throw which is short pitch for the small number of poles, and over pitch for the large number of poles. The diagram of connections is so arranged that for the small number of poles the winding is connected in parallel, giving practically the same condition as any parallel winding. For the large number of poles, the winding is connected in series, which changes the direction of current through part of the coil groups, causing consequent poles to appear, of twice the number and of half the size. In Fig. *a* for four poles, connect *A*, *B*, and *C* to the line, putting all the coils in series. For two poles, connect *A*, *B*, and *C* together and connect *A*1, *B*1 and *C*1 to the line.

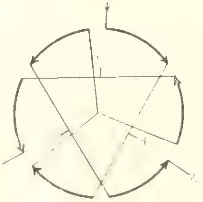


Fig. 1862(a)

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

MARCH 1920

Key for Railway Equipment Repairs

In connection with making out reports of trouble and repairs on their equipment, one operating company in the middle west has used for the past eight years a scheme of numbering the various equipment and detail troubles, which their trainmen and foremen use when making out their written reports. This idea commends itself for the following reasons:—

a—It simplifies reports.
b—It tends toward uniformity and system.
c—It saves time and labor.
d—It requires less space.
e—It appeals to the men—less writing.

Believing that this plan will interest other operators, it is given in detail below with a suggested change in numbering which lends itself more readily to systematic expansion, as each group of details is designated by a letter and then numbered from one up.

MOTORS

M- 1 Armature grounded
M- 2 Armature open circuited
M- 3 Armature short-circuited
M- 4 Armature bucking
M- 5 Armature head or hood torn
M- 6 Armature blowing fuses
M- 7 Armature bands
M- 8 Armature inspected
M- 9 Armature bearings
M-10 Armature bearings melted
M-11 Armature bearings shimmed
M-12 Armature bearings oiled
M-13 Armature shaft bent
M-14 Armature shaft broken
M-15 Armature shaft collar or wiper loose
M-16 Armature shaft key loose
M-17 Commutator worn out
M-18 Commutator needs turning
M-19 Commutator loose
M-20 Brushholder repaired
M-21 Brushholder changed
M-22 Brushholder wire burnt off
M-23 Brushholder yoke repaired
M-24 Brushholder yoke changed
M-25 New carbons
M-26 Field grounded
M-27 Field short-circuited
M-28 Field wire burnt off
M-29 Field coils put in (location and No.)
M-30 Motor taken out (type)
M-31 Motor put in (type)
M-32 Ground wire repaired
M-33 Motor frame broken
M-34 Hinge bolts put in (size and No.)
M-35 Suspension bolts
M-36 Suspension bar
M-37 New axle bearings
M-38 Shimmed axle bearings
M-39 Axle bearings oiled
M-40 Pinion loose
M-41 Pinion broken
M-42 Pinion put on
M-43 Gear loose
M-44 Gear broken
M-45 Gear put on
M-46 Gear case loose
M-47 Gear case broken
M-48 Gear case bracket (front or rear)
M-49 Gear case bolts put in (size and No.)

ELECTRIC EQUIPMENT

E- 1 Controller repaired
E- 2 Controller changed (type)
E- 3 Connection box repaired
E- 4 Connection box changed (type)
E- 5 Junction box repaired
E- 6 Junction box changed (type)
E- 7 Fuse box repaired
E- 8 Fuse box changed (type)
E- 9 Resistance repaired
E-10 Resistance changed (type)
E-11 Resistance wire repaired
E-12 Overhead switch repaired
E-13 Overhead switch changed (type)
E-14 Lightning arrester repaired
E-15 Lightning arrester changed (type)
E-16 Cables repaired
E-17 Conduit repaired
E-18 Trolley rope
E-19 Trolley wheel worn out
E-20 Trolley pole
E-21 Trolley stand repaired
E-22 Trolley stand changed (type)
E-23 Trolley catcher repaired
E-24 Trolley catcher changed (type)

WHEELS AND AXLES

W- 1 Wheel flat
W- 2 Wheel broken
W- 3 Wheel worn out
W- 4 Wheel loose
W- 5 Wheel double flange
W- 6 Wheel chip flange
W- 7 Wheel broken flange
W- 8 Axle broken
W- 9 Axle bent
W-10 Axle collar loose
W-11 Axle collar put on
W-12 Journals hot
W-13 Journals repaired
W-14 Journals oiled

BRAKES

B- 1 Brakes repaired (specify what part)
B- 2 Brakes adjusted
B- 3 Brake hanger repaired
B- 4 Brake rod stripped
B- 5 Brake rods broken
B- 6 Brake shoe broken (location)
B- 7 Brake shoe worn out (location)
B- 8 Brake shoe trimmed (location)
B- 9 Brake shoe turned (location)
B-10 Brake shoe head put on (type)
B-11 Brake cylinder repaired
B-12 Brake cylinder changed (type)
B-13 Grinders on
B-14 Grinders off
B-15 Air fittings repaired
B-16 Air cylinder cleaned and oiled
B-17 Air compressor oiled
B-18 Air compressor changed (type and No.)
B-19 Air compressor armature changed (type and No.)
B-20 Air compressor brush yoke repaired
B-21 Air compressor brush yoke changed
B-22 Air compressor carbon put in
B-23 Air compressor fields changed (No.)
B-24 Air governor repaired
B-25 Air governor changed (type)
B-26 Engineer's valve repaired
B-27 Engineer's valve changed (type)
B-28 Engineer's valve oiled

TRUCKS

T- 1 Journal box repaired
T- 2 Journal box shimmed
T- 3 Journal yoke repaired
T- 4 Journal yoke changed
T- 5 Journal bearings changed (type)
T- 6 Bolster repaired (truck or body)
T- 7 Bolster oiled
T- 8 Rub irons repaired
T- 9 Rub irons changed
T-10 Truck springs repaired (No. and type)
T-11 Truck springs changed (No. and type)
T-12 Check plates put on (No. and type)
T-13 Pilot boards repaired
T-14 Pilot boards put on

CAR BODY AND DETAILS

C- 1 Light circuit repaired
C- 2 [illegible] signal bells repaired
C- 3 Electric heater repaired
C- 4 New batteries (No.)
C- 5 Head light [illegible]
C- 6 Head light repaired
C- 7 Sand box repaired
C- 8 Sash repaired
C- 9 Window sash repaired
C-10 Curtains repaired
C-11 Dash repaired
C-12 Vestibule repaired
C-13 Panel repaired
C-14 Ventilator repaired
C-15 Hoods repaired
C-16 Hood sign repaired
C-17 Bell rope repaired
C-18 Signal bell repaired
C-19 Foot gong repaired
C-20 Gate repaired
C-21 Rear doors repaired
C-22 Handles repaired
C-23 Seats repaired
C-24 Guard rail repaired
C-25 Steps repaired (end)
C-26 Draw bar repaired
C-27 Draft rigging repaired
C-28 Draft rigging changed
C-29 Front door repaired (intermediate)
C-30 Front exit door repaired (P. A. Y. E. cars)
C-31 Car washed
C-32 Car sand papered
C-33 Car primed
C-34 Car coated
C-35 Car varnished
C-36 Car striped
C-37 Car puttied
C-38 Car burned off
C-39 Car transferred
C-40 Stove repaired
C-41 Hot water pipe repaired
C-42 Running board repaired

FENDERS

F-1 Fenders repaired
F-2 Fenders put on (type)

SWEEPERS

S-1 Sweeper brooms repaired
S-2 Broom motor repaired

JOHN S. DEAN

PERSONALS

Mr. A. M. Dudley of the industrial engineering department of the Westinghouse Electric & Mfg. Company has been appointed manager of the automotive equipment engineering department of the Company.

Mr. W. S. Rugg, manager of the railway sales department of the Westinghouse Electric & Mfg. Company, has been appointed assistant to vice-president. He will also continue in charge of the marine department of the Company.

Mr. P. M. Downing, chief engineer of the Pacific Gas & Electric Company has been elected vice-president of the Company in charge of electrical operations.

Mr. George M. Eaton, formerly in charge of the railway engineering department of the Westinghouse Electric & Mfg. Company has been made chief mechanical engineer of the Company.

Mr. D. H. Colcord, formerly of the Westinghouse Air Brake Company, department of publicity has been appointed director of research engineering of the Square D Company of Detroit, Mich.

Mr. J. M. Hipple of the industrial engineering department of the Westinghouse Electric & Mfg. Company, has been appointed manager of the industrial and railway motor engineering department.

Mr. George D. Piper, formerly director of works accounting of the Westinghouse Electric & Mfg. Company, has been elected assistant auditor of the Company by the board of directors.

Mr. Wm. T. Poulterer has resigned from The Philadelphia Electric Company Supply Department to accept the position of electrical engineer of the Electrical Development & Machine Company of Philadelphia, Pa.

Mr. A. B. Cole has been made assistant manager of the publicity department of the Westinghouse Electric & Mfg. Company and in this capacity will have complete charge of the publicity and promotion work of the Westinghouse Electric International Company.

Mr. R. A. Neal has been appointed manager of the switch section of the Westinghouse Electric & Mfg. Company at the East Pittsburgh works to succeed Mr. T. A. McDowell who was recently made manager of the cost and development section.

Mr. Thomas N. Mehan, formerly with the Electric Appliance Company, is now a member of the sales organization of the Paul W. Koch Company of Chicago.

Mr. C. H. Froebel, of the Dallas office of the Westinghouse Electric and Mfg. Company, has been appointed manager of the Houston branch office.

TRADE NOTES

—The Gurney Ball Bearing Co., Jamestown, N. Y., has issued a helpful engineering bulletin giving a number of specific instances of the use of ball bearings in machine design. It is profusely illustrated with examples of both the ordinary and the very difficult problems that have been successfully solved by the use of ball bearings. Particular attention is called to the fact that wherever radical and thrust loads occur in a shaft, they are taken care of by a single bearing with a single row of balls. It will be remembered that Mr. F. W. Gurney was the first to bring out a radial-thrust bearing of this type. This was sold in the face of strong opposition from the supporters of the old theory that radial and thrust loads must be carried on separate bearings. That the consensus of opinion on this point among engineers and bearing manufacturers is now in full accord with Mr. Gurney's radio-thrust principle is proven by the fact that practically every manufacturer of ball bearings is producing a bearing of this type.

This latest Gurney bulletin emphasizes the fact that Gurney Ball Bearings are rated with considerably higher load carrying capacity than other ball bearings of equal size. The reason for this high rating is very clearly pointed out and is shown to be due to the fact that in Gurney Bearings there are the maximum both in number and size of balls possible in a single row bearing. Another reason for their greater load capacity is the grinding of the race contour to a very close approximation of the contour of the balls themselves, thus greatly increasing the load supporting surface.

Gurney Ball Bearings are assembled by a patented process developed in the Gurney Plant, which makes it possible to assemble the greatest number of maximum size balls into the bearing without the use of a filling slot or other similar expedient. Engineers or others who are interested in the carrying of shafts upon bearings which permit axial stability and at the same time rotation with a minimum of friction, will secure data of considerable value to them in their work from this bulletin. A copy will be gladly sent by Gurney Ball Bearing Co., upon request.

The Electric Storage Battery Company of Philadelphia have gotten out an interesting booklet entitled "15 points on Ironclad=Exide Storage Batteries" showing numerous applications of these batteries in railway and wharf haulage and in mines, along with details regarding battery construction. Copies of this booklet will be mailed on requests to the Company.

LOCOMOTIVE TYPE AMPERE-HOUR METER

The experience of the past few years in the operation of storage battery trucks, tractors and battery mine locomotives has clearly demonstrated that the chief problem in the operation of these devices is the problem of the storage battery. Accordingly, the ampere-hour meter, which is the only device that automatically gives a true indication of the state of charge of the storage battery at all times and automatically terminates the charge at the proper time, is of special importance in this connection. A new locomotive type ampere-hour meter has just been designed by Sangamo Electric Company in order to meet the severe requirements as to overload and vibration experienced in this particular service.

The ampere-hour meter when installed permanently in the storage battery circuit on the truck, tractor or locomotive, registers every ampere-hour which the battery discharges in driving the vehicle, and since the total battery capacity is indicated by the red "Empty" hand on the meter, the black hand indicates the remaining capacity left in the battery. The operator then knows at all times how much farther he can run the truck. When the battery is later put on charge the ampere-hour meter registers as the charge proceeds, operating in a direction reverse from that of discharge. When the battery has been fully charged the meter will register zero and make contact within the meter, which trips circuit breaker in the charging circuit.

No battery is 100 percent efficient. More charge must be given than was taken out on the previous discharge, so there must be a certain amount of excess charge each time the battery is charged. This feature is automatically provided for in the locomotive type ampere-hour meter by means of a variable resistor device, which causes the meter to run slower by any desired percentage on charge than on discharge for equal current flow. This automatically provides that the battery will be given any desired percentage of overcharge, for by the time the meter indicating hand gets back to the full charge position, all of the previous discharge plus a certain percentage overcharge (depending upon the setting of the variable resistor element) will have been put back into the storage battery. This feature is entirely automatic, and once the resistor has been set at the desired percentage of overcharge, no further attention need be given the device.

The locomotive type meter which has been especially designed to meet the severe requirements of mine locomotive and industrial truck service embodies several distinct improvements over previous Sangamo ampere-hour meters.

1—*Overload capacity increased.*—The locomotive type meter will carry 300 percent load continuously and 500 percent load for three minute periods without undue heating of any parts.

2—[illegible] by means of improved binding posts, terminals and soft rubber gasket in the case.

3—*New type contact at zero.*—This is mounted entirely back of the dial and operates on cam principle instead of lever as formerly, thereby reducing drag on meter and increasing reliability of the action of the contact.

4—*Modified motor element.*—Special treatment is given to both the armature disc and armature box interior which has reduced the formation of mercury dross to about ¼ of that formerly experienced. This will probably improve the meter operation very greatly and eliminate trouble due to meters being slow on account of dross.

5—*Reset made dust proof.*

6—*Lock washers* throughout and special rugged construction combined with mercury floatation of the rotating element.

NATIONAL SAFETY SECTION

FIRE EXTINGUISHMENT

Practically every fire can be extinguished within the first five minutes, if proper equipment is brought into use, by men who know how to use it. Successful extinguishment of fires does not, in general, require elaborate, expensive equipment; the essentials are the right kind of equipment (suited to the existing hazards), kept in good condition in the right place, men who know how to use it, and that it be brought into use immediately after the fire starts.

No matter how well equipped a plant is with fire-fighting apparatus, nor how well-trained the men may be to handle this apparatus, it is of the utmost importance that the public fire department be notified immediately when fire is discovered, in addition to the efforts with private equipment. When men rely wholly upon their own ability to extinguish small fires, serious losses often result which could have been prevented had the public fire department been notified promptly.

SPRINKLERS

The automatic sprinkler is considered the most important of all fire-extinguishing apparatus. The design and installation of sprinkler systems cannot be described in a brief article. When painting or calcimining the ceiling or overhead piping, it is advisable to cover each sprinkler head with a small paper sack, care being taken to remove such sacks when the work is done. Paint may so affect the sensitiveness of the solder that heads will not operate except at a much higher temperature than intended.

Water shut off from sprinkler pipes is the most frequent cause of unsatisfactory control of fire by automatic sprinkler systems. Inspections often reveal that the control valves are closed and that therefore the sprinklers would be practically valueless in case of fire. A safeguard against this contingency is to seal or strap the water control valves in open position; this will tend to prevent malicious or careless closing of the valves. An electrical singnaling device which, whenever the normal position of any valves is disturbed, will automatically signal a central control station, is also an efficient safeguard against closed valves.

Another very serious condition, which often results in the failure of sprinklers efficiently to control a fire, is caused by the piling of stock, and building of shelving and partitions too close to the sprinkler heads, so that they obstruct the proper distribution of water over the surrounding area. At least twenty-four inches clear space should be maintained below the sprinklers so that an effective spray action of the heads will be possible.

HOSE

It is almost impossible to tell good from bad rubber-lined hose when it is new, either from its appearance or by putting it under pressure. It is recommended therefore that only hose bearing the label of approval of Underwriters' Laboratories be purchased.

The high cost of good hose and the importance of its being in good condition at all times demand that it be given the best of care. Hose should not be kept in a pump house, boiler house, or other warm places, as rubber quickly deteriorates under such conditions. Where hose is folded on shelves or racks it should be changed from time to time with bends at different points to prevent cracking.

WATER PAILS

Cone or round bottom pails are preferred by many, as they are less likely to be used for other purposes. The flat-bottom pail (bucket) of about three gallons capacity is however recommended, for if an employee carries two pails to a fire he may set one down while he empties the other. Fire pails, water barrels and water casks should be painted red with the word "Fire" in white letters on them. Their use for purposes other than fire-fighting should be strictly prohibited.

SODA-ACID EXTINGUISHERS

The soda-acid extinguisher in common use employes a solution of about a pound and a half of bicarbonate of soda to two and a half gallons of water, with an inner container of approximately four ounces of sulphuric acid. These are made in the "loose stopple" and the "break bottle" types. The latter are especially adapted for railroad and boat service where swaying and rocking would splash the acid over into the soda solution thus rendering it useless By inverting the extinguisher, or breaking the bottle the acid is emptied into the soda solution, forming a gas the expansion of which forces out the solution under considerable pressure.

These extinguishers are valuable in free burning fires where there is much draught. They are also of value in fighting fire on ceilings or between walls where it cannot be reached by fire pails. Sizes larger than two and one-half gallons capacity are not recommended because of the inconvenience in handling. Soda-acid extinguishers must be protected against freezing and for this reason are of little value in locations where protracted cold spells prevail. Cabinets (felt or asbestos lined) containing a small electric light beneath the extinguisher, will be adequate protection against the cold. A red glass in the door of the cabinet, through which the light may be seen will serve to mark the location of the extinguisher box. Calcium chloride cannot be used in the soda-acid extinguisher, as it reacts with the soda. The use of salt is not advisable because a fire extinguisher of this type does not operate efficiently, and also because the salt will crystallize on the sides and may corrode the extinguisher. These crystals are apt to clog the outlet, thus causing the weakened tank to explode when used. The soda solution also may form crystals on the inside wall of the extinguishers and for this reason should be examined occasionally to see that this condition does not exist.

The acid in the extinguisher constantly absorbs water and, in time, enough water may be absorbed to cause the acid to run over, and acid dropping into the tank will eat into the side of the tank around the water line. It is advisable, then, that new acid be placed in the bottle once each year when extinguisher is recharged. Soda-acid extinguishers should be recharged at least once a year. They should be emptied by inverting and playing through the hose as if on a fire, to insure the operation of the extinguisher and also to give employees an opportunity to see how they are operated. Before recharging, the hose and the extinguisher tank should be thoroughly washed.

CARBON TETRACHLORIDE EXTINGUISHERS

Carbon tetrachloride when heated to about 200 degrees F. is transformed into a gas heavier than air. When thrown on a fire the gas surrounds the fire area, keeping out the air and oxygen, and tends to smother the fire. As the extinguishing value of carbon tetrachloride depends on the smothering effect of the gas, these extinguishers are of little value where there is a wind or other air current which will carry the gas away from the fire. A fire in freely-burning material, such as wood or paper, quickly creates a strong draft of air inward and upward, and such fires are difficult to extinguish with carbon tetrachloride except when they are very small. This type of extinguisher is useful however for reaching fires in partitions, and other concealed spaces.

Extinguishers containing this fluid are of particular value for electric fires, as the carbon tetrachloride is a non-conductor of electricity and will not injure electrical apparatus. The stream may be directed on the commutator of a dynamo without danger to operator or dynamo. Carbon tetrachloride extinguishers are recommended for electric cranes, at motors (whenever located) and at convenient points in power houses. Carbon tetrachloride does not deteriorate with age, nor freeze at usual temperatures, and if mixed with a small percent of certain other ingredients will withstand a temperature of 50 degrees below zero.

Although there is a question whether or not the gas itself is harmful, there are instances where persons have been overcome while using the extinguishers. Carbon tetrachloride extinguishers should be tested periodically to see that the pump has not gummed, which would interfere with its free action. It is suggested that twice each year all extinguishers be tested by discharging (by pumping) all the contents into a pail. The pump should then be operated vigorously to make sure that it works freely, and that the packing is flexible. Then the fluid should be replaced, a little being added to fill the tank.

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Research and Manufacturing

Every well established manufacturing concern requires a staff of experts to diagnose and eliminate works troubles and to pass upon raw materials and finished product. If strong competition has also to be met, improvements in products and processes must constantly be made, new products added and byproducts utilized. Such advances are made through either invention or research—usually both.

In a small concern these several functions may all be vested in a single operative head who passes upon product and raw materials, cures works troubles, buys patents, develops new products and initiates all classes of improvements. But in a large complex organization such activities are highly differentiated and each is placed in the hands of a corps of experts; experts on patents and patent law, experts in management, in design, in testing and in various materials and processes. All design and testing falls naturally into an engineering department. Within this department, certain testing, the writing of specifications and the elimination of many manufacturing troubles is in the hands of trained physicists and chemists.

Scientific research is one of the youngest branches in the evolution of a large manufacturing plant. Its function is to obtain the fundamental, far reaching information upon which engineering development rests. Recurring works troubles and development problems frequently indicate an unknown basic principle upon which depends the clearing up of a whole series of troubles or the advance into a whole new field of development. Such fundamental principles can generally be arrived at only by patient, long continued effort on the part of experts of wide experience in a special field. The research engineer usually has neither the time nor the special scientific training to attack such recondite problems profitably; his specialty is the concrete practical problem. Nor can such research be left to the universities. University research men are not in contact with industrial research problems. Advanced students have not the time nor the experience for very difficult problems, while the instructors are chiefly interested in investigating the fundamentals of science itself. Industrial research must be cared for by the industries themselves.

The manufacturer wishes to know for example, the causes of atmospheric or of high temperature corrosion and means for combating or preventing it. Either group of problems is very complex in that the contributary factors are many and their operation obscure. Inhibitory factors are equally numerous with none of them entirely effective. Obviously not even a single specific problem in this field is to be solved in a week or a month. Magnetic aging is known to depend upon both composition and heat treatment and has been eliminated in certain products, but a great deal of research will be required to establish the limits within which it is necessary to operate. The best insulating material for a specific purpose may be selected from those available, but if new and improved materials are to be developed, extended chemical research and physical testing of a high order must be devoted to the problem.

Scientific research must everywhere supply the foundation for engineering research as the latter supports engineering as engineering supports manufacturing. The engineer is concerned with the application of known principles and materials to practical concrete problems. It is for the research staff to supply him with the principles and with the knowledge of materials which he requires.

P. G. NUTTING

Small Turbine Development

Among the benefits derived as incidental byproducts of the great war, which offset in some small degree the terrible losses suffered, has been the rapid advance in technical development along certain lines. The small turbine business is one of those which has been benefited in this way. From a neglected and somewhat disreputable small brother of the big power-house turbine it has become an item of standardized production, with all the advantages, both to the manufacturer and the user, which quantity manufacture on a large scale entails. This was caused largely by the production of units in large numbers for government service, where reliability was a vital essential. By reason of this forced development during the war, small turbine builders were enabled to concentrate their best engineering talent on quantity production, which in turn enabled them to make use of the best of materials and still produce a commercially practical unit.

The experience gained in the adaptation of the small, single wheel turbine to such a variety of uses both on shipboard and on land, for the Government, now redounds to the benefit of commercial users. The essential characteristics of a small turbine, as described in this issue by Mr. Forde, are economical operation, fool-proof construction and ability to run for long periods with a minimum of shut downs or repairs. The strenuous exigencies of the war taught our manufacturers to build machines having such characteristics, which are now being called for by central station managers in rapidly increasing quantities.

CHAS. R. RIKER

Auxiliary Rotating Apparatus

For the Chicago, Milwaukee & St. Paul Locomotives

R. E. Ferris

THE AUXILIARY rotating apparatus on the new 275 ton locomotives for the Chicago, Milwaukee & St. Paul Railroad consists almost entirely of 85 volt generators or motors, the only exception being the motor for the motor-generator set. In order of weight, this apparatus is as follows:—3000 volt motor-generator set, axle generator, compressor motor, main blower motor and boiler blower motor.

The generator of the motor-generator set supplies current for train lighting and for the lights and control on the locomotives, charges the locomotive storage battery and, in conjunction with the locomotive storage battery, supplies power to drive the compressor motor during regeneration or at standstill.

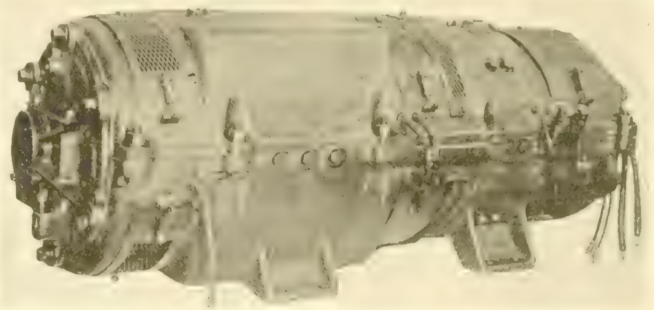

FIG. 1—3000-85 VOLT MOTOR-GENERATOR SET
Of the new 275 ton passenger locomotives for the Chicago, Milwaukee & St. Paul Railroad.

There are two axle-driven generators per locomotive, one each on the front and rear bogie trucks. These generators supply current to excite the main motor fields during regeneration; and also to drive the compressor and blower motor while the locomotive is moving, either motoring or coasting down to a certain minimum speed. The compressor motor drives a 150 foot air compressor, power being taken, as before stated, from the generator of the motor-generator set and the battery during regeneration, below a certain minimum speed, or at standstill, and from the axle generators during motoring or coasting. The main blower motors are operated during only a portion of the motoring period, and drive fans which supply forced ventilation to the main motors. The boiler blower motor drives a fan, when necessary to supply air for the burners.

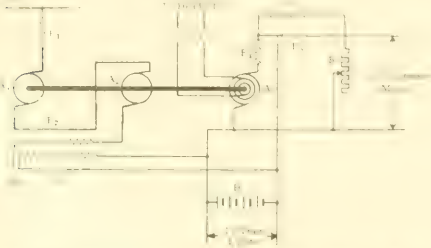

FIG. 2—[illegible] GENERATOR SET

MOTOR-GENERATOR SET

The motor-generator set consists of a double commutator, 3000 volt motor, driving a low-voltage generator on the same shaft. The motor-generator set has only two bearings, which are of the sleeve type with oil lubrication.

The motor is a bipolar, commutating-pole machine with a series and a separately-excited main field. Recognizing the severe duty imposed on a 3000 volt auxiliary motor, this machine was designed with good flashing characteristics. To obtain these characteristics the bipolar construction was selected, and the motor designed with a large air-gap, thus giving a heavy field compared to the armature. A motor main pole is shown in Fig. 4.

The armature has 41 slots and each commutator 205 bars, this combination again making for good flashing characteristics. The two windings on the armature are entirely separate, being connected in series external to the armature. The motor insulation has a large factor of safety, as is shown in the brushholder and commutator construction, Figs. 5 and 6.

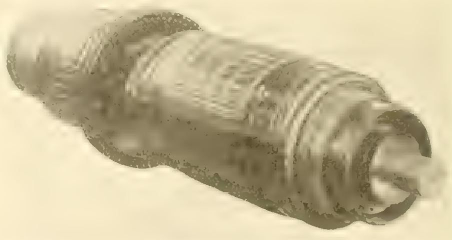

FIG. 3—ROTATING ELEMENT OF 3000 VOLT MOTOR-GENERATOR SET

The generator is a four pole, commutating-pole machine, designed to operate at approximately 85 volts. The main field is composed principally of a winding separately excited from the storage battery and in addition has a light series winding. This series winding is connected in series with the compressor motor, in order to maintain a more nearly constant voltage when the compressor cuts in or out.

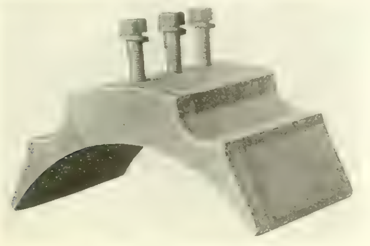
FIG. 4—MOTOR MAIN FIELD POLE

A diagram of connections of the motor-generator set is given in Fig. 2, in which A_1 is the high-tension motor armature, A_2 the low-tension motor armature, A_3 the generator armature, F_1 the motor commutating field, F_2 the motor series field, F_3 the motor separately-excited field, F_4 the generator commutating field, F_5 the generator separately-excited field, F_6 the generator field in series with the compressor motor, R the voltage regulator on the generator and B the locomotive storage battery.

The voltage of the generator is held approximately constant under varying speed and load by a regulator, which automatically adjusts the separately-excited generator field. The generator is also equipped with two slip rings, from which alternating current is supplied to the head light through a transformer which reduces the voltage to the proper value. The generator armature is of the same diameter as the motor armature and also has 41 slots. The commutator has 81 bars. Fig. 7 gives a view of the generator end housing and brushholder, showing the unit brushholder construction. The same type of brushholders are used on the blower and compressor motor, as on the generator of the motor-generator set.

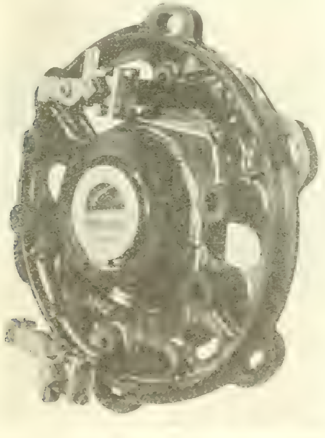
FIG 5—END HOUSING, HIGH VOLTAGE END
Showing motor main brush holder insulation

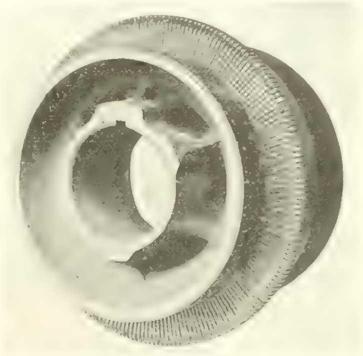
FIG 6—REAR END OF HIGH VOLTAGE COMMUTATOR
Showing insulation and creepage distances

The motor-generator set as a whole is self-ventilated by means of a fan mounted on a shaft between the motor and generator armatures. This fan draws air through ventilated covers on the outside end of the motor over the motor armature and around the motor field, expelling it at the center of the machine. The same fan also draws air from the generator end through a ventilating cover over and through the armature, and around the field coils, expelling the air at the same outlet as the air from the motor end, as shown in Figs. 2 and 3. The operating characteristics of the motor-generator set are shown in Fig. 8, while Fig. 9 shows the output of the generator at two voltages under reduced line voltage.

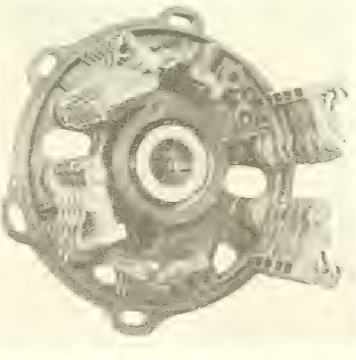
FIG. 7—[illegible]
Showing construction of brushholder unit and head light brushes for slip rings

AXLE GENERATOR

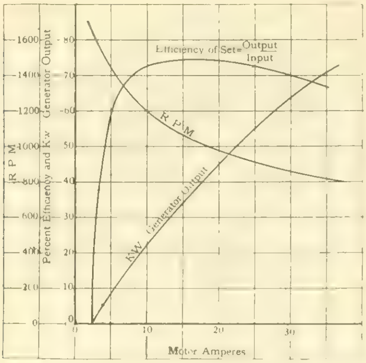

FIG. 8—OPERATING CHARACTERISTICS OF THE MOTOR GENERATOR SET

The axle generator is, to all outward appearances, nothing more than a standard, axle-mounted, nose-suspension, railway motor, as shown by Fig. 10. It is wound for 90 volts normal voltage, and large current capacity. The armature, therefore, as shown by Fig. 11, is quite different actually and in appearance from a railway motor armature. The frame is cast in one piece and bored for end housing seats. The end housings are arranged for standard oil waste lubrication. In fact, the mechanical construction of the axle generator is almost an exact copy of existing standard railway motors.

The fields of the two axle generators on each locomotive are separately excited from the locomotive storage battery. This excitation is under the control of the engineer during regeneration, but is automatically controlled during motoring to give 90 volts at the axle generator. The generator is equipped with four commutating poles wound from flat copper strap, insulated between turns with asbestos.

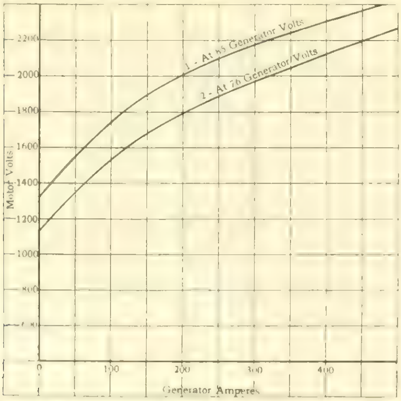

FIG. 9—MAXIMUM GENERATOR OUTPUT AT REDUCED MOTOR VOLTAGES

The axle generator armature is 16.25 inches in diameter, has 33 slots and 99 commutator bars. Owing to the large current, 450 amperes nominal rating, the commutator is quite long. This length, however, is partly due to the use of only two brushholder arms, to facilitate inspection. The armature is equipped with a fan which is used to give internal air circulation only, as the axle generator is completely enclosed as a precaution against snow.

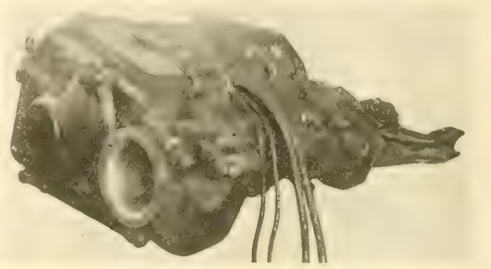

FIG. 10—LOW VOLTAGE AXLE GENERATOR

COMPRESSOR AND BLOWER MOTOR

The compressor motor and the motor which drives the fan to furnish air to the main motors are identical and interchangeable. The motor has, however, a tapped field. When used as a blower motor it is connected on full field, but when driving the compressor it is connected on the short field. The motor is wound for 90 volts and operates at a speed of approximately 1200 r.p.m. It is a standard, commutating-pole, series-wound, low-voltage motor with ventilating features, which give a very low weight per horse-power output. Especially is this the case when the motor is used to drive the compressor, as in this case a fan is mounted on the coupling to the compressor which draws air through the motor in large volumes. Fig. 12 gives a view of the motor coupled to the compressor.

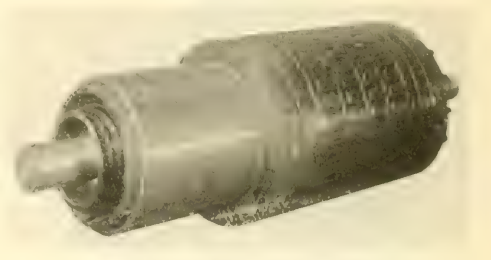

FIG. 11—AXLE GENERATOR ARMATURE
Showing long commutator for heavy current capacity.

The boiler blower motor, shown in Fig. 13, is a standard, low-voltage, series-wound motor and needs no particular description. In fact the striking feature of all the auxiliary rotating apparatus on the Chicago, Milwaukee and St. Paul locomotives, with the exception of the motor of the motor-generator set, is its conformity to standard practice.

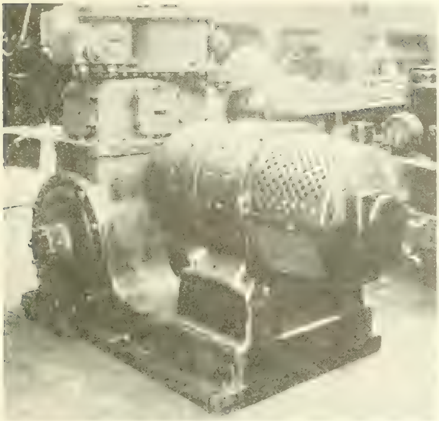

FIG. 12—LOW VOLTAGE MOTOR COUPLED TO COMPRESSOR

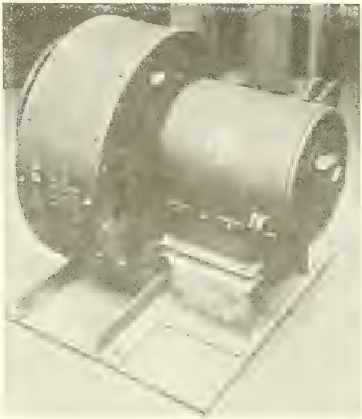

FIG. 13—MOTOR DRIVEN BOILER BLOWER

Switchboard Meter Connections for Alternating Current Circuits-IV

Single-Phase Wattmeters on Three-Phase, Three-Wire Circuits

J. C. Group

It is evident from the discussion of the measurement of power in a three-phase circuit with a polyphase wattmeter, that if a single-phase wattmeter is connected in place of each element of the polyphase meter, the algebraic sum of the two single-phase meter readings will represent the correct power. Connections for two single-phase wattmeters or watthour meters, when used in this manner, are shown in Fig. 45. For a balanced load, the two meter readings are equal only for unity power-factor, and for angles of lag or lead greater than 60 degrees, one meter reading becomes negative.

Standard current transformers are designed so that, for rated full primary current, the secondary current is five amperes, and voltage transformers are designed so that, at rated primary voltage, the secondary potential is 100 volts. A single-phase wattmeter designed for use with instrument transformers, is ordinarily provided with a current coil suitable for five amperes and a voltage coil suitable for 100 volts, and is calibrated so that with five amperes flowing in the current coil and 100 volts impressed across the voltage coil, the meter will show full scale deflection. If the instrument transformers have a one to one ratio, the full scale would be 500 watts. For other ratios the scale would be marked to indicate the power represented by the product of the current and voltage on the primary side of the instrument transformers.

The curves in Fig. 46 shows the measurement in watts for each meter when connected as in Fig. 45, and the total power given by the sum of the two measurements, for a balanced load where the power-factor varies from 100 percent to zero lagging. The conditions assumed are for instrument transformers having one to one ratio and for a full load of five amperes per line at 100 volts in the three-phase circuit. The full scale of each meter is therefore 500 watts. Curve *I* represents the power measured by the left hand meter, curve *II* the power measured by the right hand meter, and curve *III* the sum of the two measurements or the total power delivered by the three-phase circuit. In the case of leading power-factors, curve *I* would represent the power measured by the right hand meter and curve *II* the power measured by the left hand meter. Curve *III* is a straight line which shows that, for a balanced load, and constant current and voltage, the power delivered by a three-phase circuit is directly proportional to the power-factor. At unity power-factor it can be

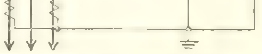

FIG. 45—MEASURING BALANCED THREE-PHASE LOADS WITH TWO SINGLE-PHASE WATTMETERS

seen from curve *III* that the total power is 866 watts which is in accordance with the standard expression for the power in a three-phase circuit, that is, $\sqrt{3}$ times the product of the line voltage and the line current. As long as the load is balanced, the ratio of the two meter readings is dependent directly upon the angle of lag or lead, so that the power-factor can be determined from the ratio of these readings for a balanced load and a pure sine wave. A curve showing the relation between the ratio of the meter readings and power-factor of the circuit is shown in Fig. 47.

The use of two single-phase wattmeters in place of the two elements of a polyphase meter on a three-phase three-wire circuit, as shown in Fig. 45, represents a very common connection for laboratory and test purposes but is seldom found on switch-boards, because the polyphase meter is much more convenient for such service. The vector analysis of the three-phase circuit for the measurement of power by the two single-phase wattmeters is the same as for the polyphase meter.

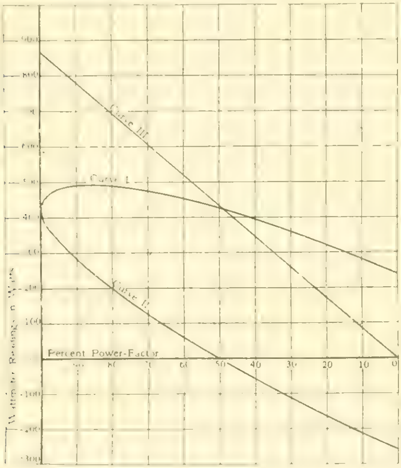

FIG. 46—DIAGRAM SHOWING POWER MEASUREMENTS OF METERS SHOWN IN FIG. 45

The power in a three-phase three-wire circuit can also be measured by three single-phase wattmeters connected as shown in Fig. 48. Three current transformers and two voltage transformers are required. A vector diagram for this arrangement, for a balanced load at unity power-factor, is shown in Fig. 49 in which $E_{1\,2}$, $E_{2\,3}$, and $E_{3\,1}$ represent the line voltages 120 degrees apart. The voltage coils of the meters are not connected across the voltage transformers but are connected in star, one end of each voltage coil being connected to a line and the other end of each coil being connected to a common neutral point. For this common point to be a true neutral, it is necessary that the voltage circuits have the same impedance, and the accuracy of the meter reading depends on the common point being a true neutral. In the vector diagram, $E_{1\,0}$, $E_{2\,0}$, and $E_{3\,0}$ represent the voltages impressed on the voltage coils of the right hand, middle, and left hand wattmeter respectively. These voltages, being 30 degrees behind the line voltages, are in phase with the line currents represented by I_1, I_2, and I_3. The power measured by the three wattmeters is equal to $E_{1\,0}$, $I_1 + E_{2\,0}\ I_2 + E_{3\,0}\ I_3$ or $3\ E_p$ I where E_p is the balanced three-phase star voltage and I the three-phase line current for the balanced load. But $E_p = 1/3 \sqrt{3}\ E$ where E is the three-phase line voltage, and therefore the power is $\sqrt{3}\ EI$ which is correct for the three-phase circuit at unity power-factor. For balanced loads the three wattmeter readings are equal at any power-factor, each being $1/3 \sqrt{3}\ E\ I \cos\phi$ where ϕ is the angle of lag or lead.

The three-single phase wattmeters connected as in Fig. 48, correctly measure the power of unbalanced as well as balanced loads, as can be shown by considering the extreme case of unbalancing where a single-phase load is taken off between any two of the lines. In Fig. 50 a vector diagram is shown for the case where a single-phase load at unity power-factor is connected between lines *1* and *2*, and current flows in lines *1* and *2* but not in line *3*. I_1 represents the current in line *1* and the current which flows through the right hand wattmeter, and I_2 the current in line *2* and the current which flows through the middle wattmeter. I_1 is 30 degrees ahead of $E_{1\,0}$, and I_2 30 degrees behind $E_{2\,0}$, and therefore the power measured by the two wattmeters is $1/2 \sqrt{3}\ I_1\ E_{1\,0} + 1/2 \sqrt{3}\ I_2\ E_{2\,0}$. But for balanced voltages $E_{1\,0}$ and $E_{2\,0}$ are equal and may be represented by $1/3 \sqrt{3}\ E$ where E is the three-phase line voltage; and I_1 and I_2 are the same and therefore the expression for the power reduces to $E\ I$ which is correct for the single-phase circuit at unity power-factor. Similar reasoning will show that the middle and left hand wattmeters measure the power of a single-phase load connected between lines *2* and *3*, and that the right-hand and the left-hand wattmeters measure the power of a single-phase load connected between lines *3* and *1*.

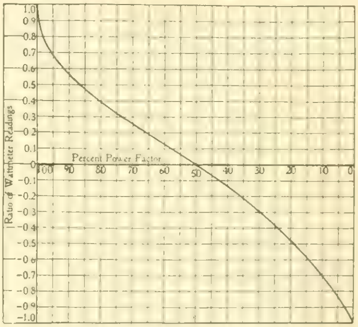

FIG. 47—CURVE FOR DETERMINING THE POWER-FACTOR OF A BALANCED THREE PHASE LOAD FROM THE RATIO OF METER READINGS

For a single-phase load connected between lines *1* and *2*, if the current lags by an angle ϕ, it is evident from the vector diagram, Fig. 50, that the power measured by the right-hand wattmeter, expressed in terms of the three-phase line voltage and line current, is $1/3 \sqrt{3}\ E\ I \cos\ (30 - \phi)$, and the power measured by the middle wattmeter is $1/3 \sqrt{3}\ E\ I \cos\ (30 + \phi)$. The sum of the readings is $1/3 \sqrt{3}\ E\ I\ [\cos\ (30 - \phi) + \cos\ (30 + \phi)] = 1/3 \sqrt{3}\ E\ I\ [\cos 30 \cos\phi + \sin 30 \sin\phi + \cos 30 \cos\phi - \sin 30 \sin\phi] = 1/3 \sqrt{3}\ E\ I\ [\sqrt{3} \cos\phi] = E\ I \cos\phi$ which is the correct expression for the power in a single-phase circuit at any power-factor, and shows that the wattmeters correctly measure the power for an unbalanced load at any power-factor.

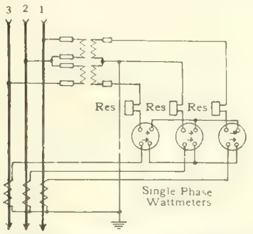

FIG. 48 CONNECTIONS FOR SEPARATELY MEASURING THE PHASE LOADS

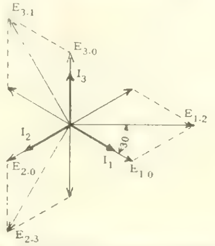

FIG. 49 VECTOR DIAGRAM OF CIRCUIT SHOWN IN FIG. 48

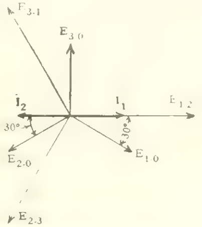

FIG. 50 VECTOR DIAGRAM, FOR A SINGLE-PHASE LOAD, OF CIRCUIT SHOWN IN FIG. 48

The power in a three-phase three-wire circuit for a balanced load may be measured with one single-phase wattmeter connected as in either Fig. 51 or Fig. 54. In Fig. 52 is shown a vector diagram for a balanced load at unity power-factor on the three-phase circuit shown in Fig. 51. $E_{1\ 2}$, $E_{2\ 3}$, and $E_{3\ 1}$, 120 degrees apart, represent the line voltages and I_1, I_2, and I_3 represent the line currents. The current transformers are so connected that the current I_M, which flows through the wattmeter, is equal to $I_3 - I_1$ (vectorially), and being 30 degrees out of phase with these currents, is equal to $\sqrt{3}$ times the line current. The voltage coil of the wattmeter is connected to the line voltage. Therefore the power measured by the wattmeter is $\sqrt{3}\ E\ I$ where E is the line voltage and I the line current, and this result is correct for the power in a three-phase circuit for a balanced load at unity power factor. For a balanced load at any power factor the meter's measurement is $\sqrt{3}\ E\ I \cos\ \phi$, where ϕ is the angle of lag or lead.

The single-phase wattmeter, connected as in Fig. 51, does not measure the power correctly for unbalanced loads as can be seen by considering the extreme case of unbalancing where single-phase loads are taken off between any two of the lines. A vector diagram for these conditions is shown in Fig. 53, in which $E_{3\ 1}$ represents the line voltage impressed on the voltage coil of the wattmeter, I_1 and I_2 represent the line currents when the single-phase load is between lines *1* and *2*, and I_1 represents the current which flows through the wattmeter. It is evident from the connections in Fig. 51 that the positive direction of I_1 through the meter is in the reverse direction with reference to the positive direction assumed for the meter coils, but it is necessary that this current be taken through the meter in this way for the vector diagram shows that I_1 is 120 degrees from $E_{3\ 1}$, and therefore the torque producing or power component of I_1, in phase with $E_{3\ 1}$ in the meter coils, is in reality that obtained by projecting $-I_1$ on the line of the voltage vector $E_{3\ 1}$, which is in the same direction as $E_{3\ 1}$ and this gives a positive meter reading. The power measured by the wattmeter in this case is $E\ I \cos 60°$ or $1/2\ E\ I$ where E is the line voltage and I the line current. The result is only one-half of the power in the single-phase circuit. I_{2A} and I_3 represent the line currents when the single-phase load is between lines *2* and *3*, and in this case I_3, 60 degrees behind $E_{3\ 1}$, represents the current which flows through the wattmeter. Therefore the power measured by the meter is $E_{3\ 1}\ I_3 \cos 60°$ or $1/2\ E\ I$, where E is the line voltage and I the line current. The result is again only one-half the correct power. I_{3A} and I_{1A} represent the line currents when the single-phase load is between lines *3* and *1*, and in this case the current I_M, which flows through the meter, is equal to $I_{3A} - I_{1A}$ (vectorially), and since the two currents are in phase, I_M equals twice the line current. I_M is in phase with $E_{3\ 1}$ and therefore the power measured by the wattmeter is $E_{3\ 1}\ I_M$ or $2\ E\ I$ where E is the line voltage and I the line current. The result is twice the actual power.

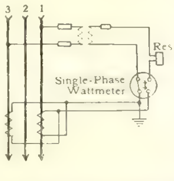

FIG. 51 MEASURING BALANCED THREE-PHASE LOADS WITH ONE SINGLE-PHASE WATTMETER

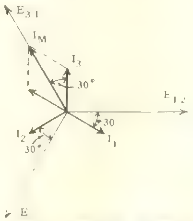

FIG. 52 VECTOR DIAGRAM, FOR BALANCED LOAD, OF CIRCUIT SHOWN IN FIG. 51

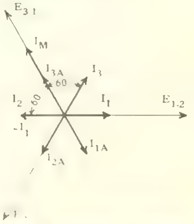

FIG. 53 VECTOR DIAGRAM, FOR SINGLE-PHASE LOADS, OF CIRCUIT SHOWN IN FIG. 51

The vector diagram, Fig. 55, is for a balanced load at unity power-factor on the three-phase circuit with the single-phase wattmeter connected as in Fig. 54. The line voltages are represented by $E_{1\ 2}$, $E_{2\ 3}$, and $E_{3\ 1}$, and the line currents by I_1, I_2, and I_3. The voltage transformers are so connected that the voltage E_M, impressed on the voltage coil of the wattmeter, is equal to $E_{2\ 3}$ —

$E_{1\,2}$ (vectorially) and being 30 degrees out of phase with these line voltages is equal to $\sqrt{3}$ times the line voltage. The current I_2 which flows through the wattmeter is in phase with E_M. Therefore the power measured by the wattmeter is $E_M\,I_2$ or $\sqrt{3}\ E\ I$ where E is the line voltage and I the line current, and this result is correct for the power in a three-phase circuit for a balanced load at unity power-factor. For a balanced load at any other power-factor, the meter measurement is $\sqrt{3}\ E\ I\ cos\phi$ where ϕ is the angle of lag or lead, and this also is correct.

The single-phase wattmeter connected as in Fig. 54 does not correctly measure the power of unbalanced loads, as can be seen by considering the extreme case of unbalancing where single-phase loads are taken off between any two of the lines. A vector diagram for these conditions is shown in Fig. 56, in which I_1 and I_2 represent the line currents when the single-phase load is between lines *1* and *2*, and I_2 represents the current which flows through the wattmeter. I_2 is 30 degrees out of phase with E_M and therefore the power measured by the wattmeter is $E_M\,I_2\,cos\,30°$ or $3/2\ E\ I$, where E is the line voltage and I the line current, which is not correct for the power in the single-phase circuit. Similar reasoning will show that the reading is the same for a single-phase load between lines *2* and *3* when the line currents are as represented by I_{2A} and I_3 in the vector diagram. In case the single-phase load is between lines *3* and *1*, where I_{3A} and I_{1A} represent the line currents, the meter does not measure any of the power, as the current transformer is in the line in which current does not flow.

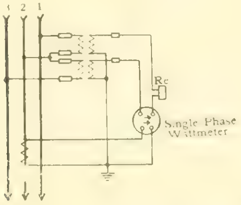

FIG. 54—MEASURING BALANCED THREE-PHASE LOADS WITH ONE SINGLE PHASE WATTMETER

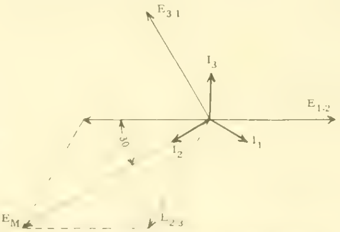

FIG. 55—VECTOR DIAGRAM, FOR BALANCED LOAD, OF CIRCUIT, SHOWN IN FIG. 54

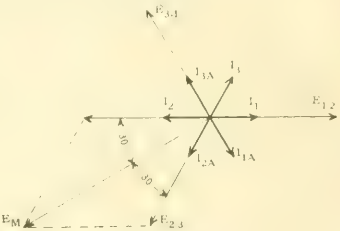

FIG. 56—VECTOR DIAGRAM, FOR SINGLE-PHASE LOADS, OF CIRCUIT SHOWN IN FIG. 54

Two single-phase meters connected as shown in Fig. 45 give equal readings only for unity power-factor. The connections shown in Fig. 57 are such that the readings of the two single-phase wattmeters are equal for a balanced load at any power-factor. To accomplish this it is necessary that one of the voltage transformers have a tap brought out at the middle of the secondary winding, and that the current transformers in lines *1* and *2* have secondary windings for one-half the current in the secondary winding of the current transformers in line *3*;—that is, if for full load the normal secondary current for the current transformer in line *3* is five amperes, the secondary current in the current transformers in lines *1* and *2* must be *2.5* amperes. A vector diagram for a balanced load at unity power-factor is shown in Fig. 58. $E_{1\,2}$, $E_{2\,3}$, and $E_{3\,1}$, 120 degrees apart, represent the line voltages, and $1/2\ E_{1\,2}$ represents one-half of the line voltage $E_{1\,2}$ or the voltage from the middle tap to an outside line on the secondary side of the voltage transformer connected between lines *1* and *2*. I_1, I_2, and I_3 represent the line currents. $1/2\ I_1$ and $1/2\ I_2$ represent the currents in the secondaries of the current transformers in lines *1* and *2*, and I_3 represents the current in the secondary of the current transformers in line *3*. The current transformers in lines *1* and *2* are so connected that the current I_R which flows through the right hand wattmeter is equal to $1/2\ I_1 - 1/2\ I_2$ (vectorially), and being 30 degrees ahead of $1/2\ I_1$ is equal to $\sqrt{3}$ times these currents and is in phase with the voltage $E_{1\,2}$. Since the voltage coil of the right hand wattmeter is connected to the voltage $E_{1\,2}$, the power measured by this meter is $E_{1\,2}\ I_R$ or $1/2\ \sqrt{3}\ E\ I$ where E is the three-phase line voltage and I the line current. I_3 represents the current which flows through the left hand wattmeter. The voltage transformers are connected so that the voltage E_L, impressed on the voltage coil of the left hand wattmeter, is equal to $E_{3\,2} - 1/2\ E_{1\,2}$ (vectorially), and is in phase with I_3. Therefore, the power measured by the left hand wattmeter is $E_L\ I_3$ or $1/2\sqrt{3}\ E_{3\,2}\ I_3$, since E_L is equal to $E_{3\,2}\ cos\ 30°$. Then omitting the sub-figures for the balanced load, the expression for the power becomes $1/2\ \sqrt{3}\ E\ I$ where E is the three-phase line voltage and I the line current. The power measured by the two wattmeters is $1/2\ \sqrt{3}\ E\ I + 1/2\ \sqrt{3}\ E\ I = \sqrt{3}\ E\ I$ which is correct for the power in a three-phase circuit for a balanced load at unity power-factor. It can be seen from the vector diagram that for any power-factor the reading of each meter is $1/2\ \sqrt{3}\ E\ I\ cos\phi$ where ϕ is the angle of lag or lead, and that the readings will not become negative before the maximum angle of 90 degrees lag or lead is reached.

The two single-phase wattmeters connected as in Fig. 57 correctly measure the power in the three-phase circuit for unbalanced loads at any power-factor, as can be explained by considering the extreme case of unbalancing where single-phase loads are taken off between any two of the lines. However, for unbalanced loads, the readings of the two wattmeters are not equal. In

Fig. 59 is shown a vector diagram for the case where a single-phase load is taken from lines *1* and *2*. I_1 and I_2 represent the line currents and are shown lagging by an angle ϕ in order to make the proof cover any power-factor. Current does not flow in line *3* and therefore the left hand wattmeter does not measure any power. The current I_R, which flows through the right hand wattmeter, is equal to $1/2\ I_1 - 1/2\ I_2$ (vectorially) and, since these currents are in phase, is equal to the line current. I_R is out of phase with the voltage $E_{1\,2}$ by an angle ϕ, and therefore the power measured by this meter is $E_{1\,2}\ I_R \cos\phi$ or $E\ I \cos\phi$ where E is the line voltage and I the line current, and this result is correct for the single-phase circuit.

In Fig. 60 is shown a vector diagram for the case where the single-phase load is between lines *2* and *3*. I_2 and I_3 represent the line currents and are shown lagging by an angle ϕ. The current from the current transformer in line *2* flows through the right hand wattmeter in the opposite direction from the positive direction assumed for the meter coils, but this current is $120^\circ + \phi$ out of phase with $E_{1\,2}$ and the power component in phase with $E_{1\,2}$ is that obtained by projecting $-1/2\ I_2$ on the line of the voltage vector $E_{1\,2}$, and this component being in the same direction as $E_{1\,2}$ gives a positive reading in the meter. Therefore the power measured by the right hand wattmeter is $E_{1\,2}\ 1/2\ I_2 \cos(60^\circ - \phi)$ or expressed in terms of the line voltage E and line current I is $1/2\ E\ I \cos(60^\circ - \phi) = 1/2\ E\ I\ (\cos 60^\circ \cos\phi + \sin 60^\circ \sin\phi) = 1/2\ E\ I\ (1/2 \cos\phi + 1/2 \sqrt{3} \sin\phi) = 1/4\ E\ I\ (\cos\phi + \sqrt{3} \sin\phi)$. I_3, representing the current which flows through the left hand wattmeter, is $30^\circ + \phi$ behind E_L, and the power measured by this meter is $E_L\ I_3 \cos(30^\circ + \phi)$. E_L is equal to $1/2 \sqrt{3}\ E$ where E is the three-phase line voltage, and I_3 is the line current and may be represented by I, and using these values for E_L and I_3 the expression for power becomes $1/2 \sqrt{3}\ E\ I \cos(30^\circ + \phi) = 1/2 \sqrt{3}\ E\ I\ (\cos 30^\circ \cos\phi - \sin 30^\circ \sin\phi) = 1/2 \sqrt{3}\ E\ I\ (1/2 \sqrt{3} \cos\phi - 1/2 \sin\phi) = 1/4\ E\ I\ (3 \cos\phi - \sqrt{3} \sin\phi)$. The sum of the two meter readings is $1/4\ E\ I\ (\cos\phi + \sqrt{3} \sin\phi + 3 \cos\phi - \sqrt{3} \sin\phi) = 1/4\ E\ I\ (4 \cos\phi) = E\ I \cos\phi$ which is correct for the single-phase circuit.

In Fig. 61 is shown a vector diagram for the case where the single-phase load is between lines *3* and *1*. I_3 and I_1 represent the line currents and are shown lagging by an angle ϕ. $1/2\ I_1$, representing the current which flows through the right hand wattmeter, is $60^\circ + \phi$ behind the voltage $E_{1\,2}$. Therefore the power measured by the right hand wattmeter is $E_{1\,2}\ 1/2\ I_1 \cos(60^\circ + \phi)$ or omitting the sub-figures for the line voltage and line current, the expression becomes $1/2\ E\ I \cos(60^\circ + \phi) = 1/2\ E\ I\ (\cos 60^\circ \cos\phi - \sin 60^\circ \sin\phi) = 1/2\ E\ I\ (1/2 \cos\phi - 1/2 \sqrt{3} \sin\phi) = 1/4\ E\ I\ (\cos\phi - \sqrt{3} \sin\phi)$. I_3, representing the current which flows through the left hand wattmeter is $30^\circ - \phi$ ahead of E_L. Therefore the power measured by the left hand wattmeter is $E_L\ I_3 \cos(30^\circ - \phi)$ or expressing E_L and I_3 in terms of line voltage and line current is $1/2 \sqrt{3}\ E\ I \cos(30^\circ - \phi) = 1/2 \sqrt{3}\ E\ I\ (\cos 30^\circ \cos\phi + \sin 30^\circ \sin\phi) = 1/2 \sqrt{3}\ E\ I\ (1/2 \sqrt{3} \cos\phi + 1/2 \sin\phi) = 1/4\ E\ I\ (3 \cos\phi + \sqrt{3} \sin\phi)$. The sum of the two meter readings is $1/4\ E\ I\ (\cos\phi - \sqrt{3} \sin\phi + 3 \cos\phi + \sqrt{3} \sin\phi) = E\ I \cos\phi$ which is correct for the single-phase circuit.

It can be seen from the vector diagrams in Figs. 60 and 61 that for unbalanced loads, one wattmeter reading may become negative, for in Fig. 60, if the angle of lag is greater than 60 degrees, the reading of the left-hand wattmeter is negative and in Fig. 61 if the angle of lag is greater than 30 degrees, the reading of the right-hand wattmeter is negative. Therefore it is necessary in all cases of unbalanced load to take the algebraic sum of the two meter readings to get the correct power. If the current leads instead of lags, a similar process of reasoning for the various cases will show that the final results obtained will be the same.

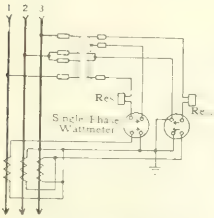

FIG. 57—CONNECTION TO SECURE EQUAL READINGS AT ANY POWER-FACTOR

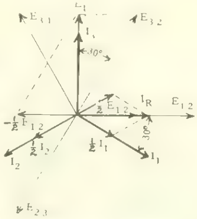

FIG. 58—VECTOR DIAGRAM, FOR BALANCED LOAD, OF CIRCUIT SHOWN IN FIG. 57

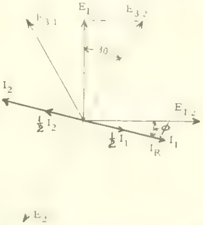

FIG. 59—SINGLE-PHASE LOAD BETWEEN LINES 1 AND 2, OF CIRCUIT SHOWN IN FIG. 57

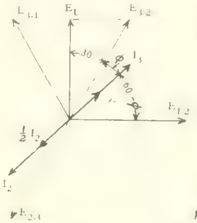

FIG. 60—SINGLE-PHASE LOAD BETWEEN LINES 2 AND 3, OF CIRCUIT SHOWN IN FIG. 57

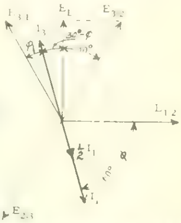

FIG. 61—SINGLE-PHASE LOAD BETWEEN LINES 3 AND 1, OF CIRCUIT SHOWN IN FIG. 57

CORRECTION

In the Journal for March, 1920, p. 102, last line above Fig. 30, (30° [illegible] φ) should have been (30° [illegible] φ).

Steam Turbines for Mechanical Drive

Ivan Stewart Forde
Manager, Small Turbine Div.,
Westinghouse Electric & Mfg. Company

ALTHOUGH small steam turbines have been in successful commercial use for at least ten years, they have, so far as the layman was concerned, remained a mystery. People felt that they were something to conjure with; apparatus that would deliver power the same as a steam engine, but in a different manner. It remained for the Great War to give the small turbine the pre-eminence and impetus it so justly deserved, and from now on this class of apparatus will continue to grow in popularity as its fundamental principles become better understood.

Some manufacturers entered the steam turbine field by first manufacturing relatively large units, and because of economic necessity entered the small turbine work also, while others began with the building of small turbines and gradually increased their sphere of influence. The net result, however, has been the same. Both classes, looking somewhat into the future, have seen the desirability of maintaining their prestige in the building of small turbines, and are today manufacturing more of them than they did during the war when, for a period of two years, the production of several plants was devoted almost exclusively to Government requirements.

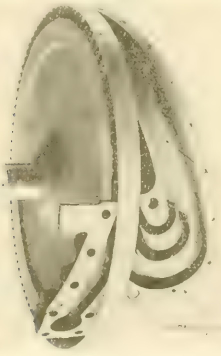

FIG. 1 PRINCIPLES OF DESIGN OF SMALL WESTINGHOUSE STEAM TURBINES

Even though the public was unable to purchase turbines during this period, the result, to a great extent, was good for both the steam turbine industry as a whole and the users of this apparatus, for the reason that the turbine builders were enabled to manufacture large numbers of standard turbines for various Governmental requirements, thus permitting quantity production, and the distribution of large numbers of turbines for marine propulsion, electric generating units and for driving centrifugal pumps and blowers, both on land and sea. The wide distribution of this apparatus, has educated the public in steam turbine practice; not only fundamental principles, but variations in the designs of different types.

The small turbine is appreciated for its simplicity and ability to operate for long periods of time without either shut-downs or repairs. And when one stops to consider, a small turbine is scarcely more complicated mechanically than an electric motor. For example, take the single wheel type making use of the re-entry principle, in which steam is directed on to the blades two or more times.

There is a single revolving element mounted between two bearings, and carrying a single row of blades. A nozzle or nozzles expand the steam and convert it from pressure into velocity as it enters the blades. The resultant effort is work, obtained from a stationary and a moving element. The steam turbine has a governor for controlling the speed, and an inlet valve under governor control for the admission of steam. Except for differing details of design, all small turbines are similar; yet it is on these relatively small, though very important details, that a dozen builders of small turbines are engaging the interest of both purchasers and the engineering profession. Despite the fact that these builders have been engaged in the manufacture of small turbines for ten years, the statement is made here in all seriousness that this work is just beginning. "Time was" when the manufacturer built one design of small turbine, and that turbine sufficed for all needs mechanical and electrical. That was when the demand was limited, and occasional orders were received for

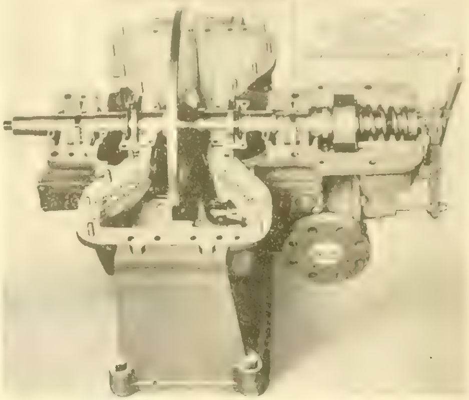

FIG. 2 SMALL TURBINE WITH COVER REMOVED
Showing all interior parts.

exciters and turbine-driven condenser pumps. Now, it is a highly specialized industry with definite, standardized requirements, and manufacturers have seen the need of building steam turbines for both mechanical work and for electric generators, each with differing though exacting requirements.

To a certain extent, the steam turbine for non-electric or mechanical drive calls for a more rigid specification than does the steam turbine for generator work. This is obvious when it is considered that the small turbine-driven exciter is mounted on the engine room floor, and cared for in as much detail as the main generating units, while the steam turbines driving the condenser pumps, boiler feed pumps and draft fans often are installed in inaccessible corners of power house basements. They are often neglected because they are far removed from the engine room floor, and in general are not given the same care and attention as the main apparatus.

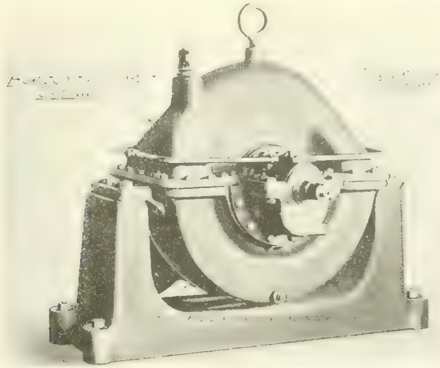

FIG. 3—EXTERIOR VIEW OF SMALL TURBINE

Showing horizontally split, "heavy duty" casing, center support feature and simple pipe connections for water seal glands.

The builder of small turbines is therefore called upon to supply a mechanical drive turbine answering very much the following specification:—

> "We want a small turbine for auxiliary drive that can be installed in a corner of our power house basement; one that can stand a fair amount of abuse or neglect. It must be economical because we need only a limited amount of exhaust steam for feed water heating. It must be capable of developing full power irrespective of whether the steam pressure is 250 or 175 pounds.
>
> "Because we cannot have an operator always in attendance, it must be provided with proper bearings with such a perfect lubricating system that it will not be necessary to shut down to rebabbit the bearings from time to time."
>
> "The governor must be strong enough to stand slight sticking of the valve or valve stem, or such other difficulties as may occur in the ordinary operation of a turbine."
>
> "The turbine must also be equipped with an emergency overspeed governor, and we do not want to be annoyed by steam leaking into the room from the interior of the turbine. To be exact, we want the best small turbine you know how to build for the very exacting service required of it; that of keeping our main units in operation through the constant operation of condenser and boiler feed pumps."

One would hardly expect that the small turbine of the past, seldom if ever operated at steam pressures higher than 150 pounds, would meet the above specification, with the added requirements of being able to operate satisfactorily on steam pressures as high as 325 pounds and superheat up to 275 degrees. Yet, that is the requirement of the small turbine of today and tomorrow for installation in large central stations to drive auxiliaries. This severe specification is being fulfilled by small turbines designed and built to meet situations of this kind, with finished details, equal in reliability to the large units.

Irrespective of whether the turbine be designed for mechanical or electric generator drive, the principles of design are identical, inasmuch they are both of the velocity type, making use of the re-entry principle, in which design the turbine depends upon the velocity of the steam for turning effort.

The revolving element of this turbine is a single wheel, the periphery of which is hollowed out to form a groove, into which a single row of blades is inserted.

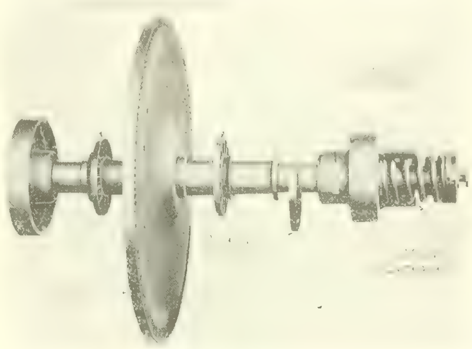

FIG. 4—REVOLVING ELEMENT

As shown in Figs. 1 and 2, steam enters through a balanced bronze inlet valve into an expanding nozzle, which converts the pressure in the steam into velocity, and then directs it onto the blades. As the steam passes through these blades, it enters a reversing chamber on the opposite side of the wheel to the nozzle, and is guided back on to the blades a second time, when additional power is obtained. As the steam passes through the blades the first time, a considerable portion of the velocity is expended, and for this reason the reversing chamber provides for this steam entering a greater number of blades in this second action, in order to compensate for the reduced velocity.

As the paramount consideration in small turbine design is reliability, the turbine manufacturer expends much effort in making his turbine answer this requirement. Starting out on the premises that the wheel is properly built, the single wheel type offers the best possibilities for both simplicity and reliability for it enables the manufacturer to eliminate the complications of a long shaft, diaphragms and packing between wheels or stages of the multistage type.

The turbine casing in Fig. 3 is what, in steam engine parlance, would be termed the "heavy duty" type, since it is intended for continuous service at maximum capacity for indefinite periods. The reader will observe a distinct departure from standard small turbine practice, as he has known it. Turbine feet are eliminated, and in their stead the turbine casing is supported at the center line by heavy supports, which in turn are connected at the bottom to form a bedplate. This feature represents the turning point in small turbine practice, and is the one outstanding development that has been offered in recent years for the betterment of the small turbine. This center support construction is copied from large turbine practice which has been uniformly successful in operation for many years, and cannot in any sense of the word be termed an experiment. The advantage of the center support feature is that the turbine casing is free to expand in all directions without in any way disturbing the alignment of the turbine and driven shafts. When the turbine is provided with feet, and these feet are bolted down solidly to a pump bedplate, it is obvious that they will not permit the turbine casing to expand in any but an upward direction, consequently throwing the turbine out of line with the driven shaft.

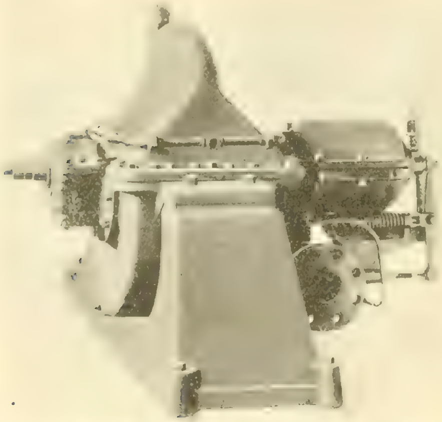
FIG. 5—ASSEMBLED VIEW OF A SMALL TURBINE

This mis-alignment was, in a measure, corrected in the past by some form of flexible coupling, and allowing for the turbine expansion in lining up the two shafts. For relatively low steam pressures, and consequently small expansion of the turbine casing, the flexible coupling sufficed, but where the two coupling halves were not a good fit and the exact amount of expansion was miscalculated, mis-alignment occurred even in the low or moderate pressure installations, and took the form of chronic bearing, packing and governor troubles. These troubles became very aggravated as the steam temperatures increased and as superheat was employed. The center support feature permits unlimited expansion in all directions, regardless of maximum steam conditions and enables the flexible coupling to perform the work it was originally intended for, namely, allow for axial or horizonal movement. Of the large number of these turbines now in service with this center support feature, not a single case of mis-alignment trouble has occurred.

The rotor is a steel forging, with a materially increased section at the center or hub, in order to make the stress as uniform as possible when rotating. The shaft is also a steel forging, and as shown in Fig. 4, is uniform in dimensions. The rotor is forced onto the shaft with a taper fit, under heavy hydraulic pressure, thus assuring a positive fit.

The blades are of a special composition, known as electric furnace nickel steel. Actually, this metal consists of iron smelted in an electric furnace in order to get a pure and high grade iron, to which is added a high percentage of nickel, thus increasing its tensile strength and making it better able to withstand erosion. This ability to withstand erosion is of course, a most important characteristic of blading material. It is particularly important in view of the ever-increasing number of stations operated under high temperature steam, and this special metal assures long blades a life under severe conditions. The ordinary riveted shroud is dispensed with, and each blade is shaped in such a manner that the tips of the blades themselves form a shroud, so that when all of the blades are inserted a perfect band or shroud is formed.

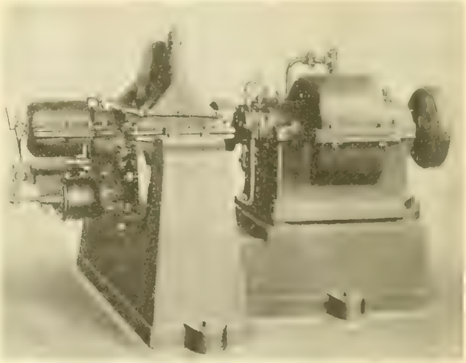
FIG. 6—VIEW OF STEAM TURBINE AND REDUCTION GEAR
Showing the heavy bedplate, center support features and forced lubrication.

The turbine manufacturer must give special attention to the design of small parts, such as the bearings, glands, governor, inlet valve and emergency overspeed governor; for, regardless of how well built the casing, rotor and shaft may be, if the small parts give trouble, the turbine cannot be considered satisfactory. The operator wants his auxiliary troubles to be few and far between; he wants continuous operation, because the main units in the station are dependent upon the auxiliary turbines. Therefore, in selecting a turbine for this work, those features so necessary for continuous operation, should be carefully investigated.

A steam engine has its stuffing box, and the steam turbine its glands. Sometimes these glands are called shaft packing or shaft seals. It is obvious that, where the shaft extends outside the casing at either end, it is impossible to have the casing and shaft fit in such a manner that there will be no leakage of steam past the shaft into the engine room, because of a greater pressure in the interior of the turbine than on the outside. The shaft and casing at this point must therefore be sealed or packed so that steam will not escape. Several forms of packing are used to accomplish this purpose.

The type of gland used for sealing purposes in the turbines illustrated, is the essence of simplicity, since it consists of a bronze centrifugal runner fitted to the turbine shaft. This gland, revolving in water at turbine speed (fitted in a gland case at either end of the turbine casing) builds up a water wall so solidly that it acts as a perfect seal both against high back pressures and high vacuum. The water seal gland has no rubbing contact, and therefore shaft packing maintenance is not only eliminated, but the greater annoyance and inconvenience of shut downs for replacing shaft packing is also dispensed with.

The bearings have also been given special consideration. They are far removed from the turbine casing, thus permitting them to remain cool regardless of the temperature in the interior of turbine casing. Each bearing is provided with a large oil reservoir with a very substantial single oil ring. The governor is of the shaft type, very powerful, and by means of a nonbinding governor lever works directly onto a bronze, balanced, steam inlet valve.

Because these auxiliary turbines are often installed in inaccessible places, there is the natural tendency to "let well enough alone", so long as the turbine operates. Therefore, in order to make them 100 percent reliable and fool-proof, each turbine, regardless of whether the capacity is 10 or 500 horse-power, is equipped with an emergency overspeed governor, which will instantly shut off the steam should it show a disposition to overspeed. Often, this overspeeding will take place through no fault of the turbine, such as a pump losing its water and speeding up far beyond the range of any governor control, in which event the emergency overspeed governor comes into action and closes the steam valve.

Small turbines have now gone through the development stage, as is evident from the many common sense features incorporated in their design. Note the modern construction:—a heavy cast-iron casing, horizontally split for easy inspection, and supported at the center line; a forged steel rotor with electric furnace nickel steel blades; a bronze nozzle and reverser properly dimensioned by hand for accuracy; water seal glands; a powerful governor; an emergency overspeed governor; properly designed bearings; a balanced inlet valve made of bronze;—all these things make for reliability. Added to these features is the fact that turbines can be equipped with two nozzles, one for high pressure and the other for low pressure.

Turbines adapt themselves very readily to all forms of driven apparatus. They can be direct connected to boiler feed pumps, for instance, by the center support connecting piece resting directly on the base of the pump bedplate; the two shafts then being lined up by means of the usual coupling. Where space is an important consideration, the pump bedplate can be materially shortened by bolting directly to the center support bedplate. In the case of geared units, a continuous box type bedplate is provided, the front part of the bedplate being cast to form the two center supports for the turbine. This bedplate can then be bolted to the pump bedplate if desired. When a turbine and gear are connected together, the inboard bearing on the turbine is omitted and the turbine and pinion shafts are bolted solidly together, thus giving to all intents and purposes a single revolving element of turbine and gear. A forced feed geared oil pump is provided on each gear, so that when furnished in connection with one of these turbines, both the gear and turbine are provided with forced lubrication.

The Story of the Insulations

C. F. Skinner

IN THE CHAIN of apparatus and devices which connect the ultimate consumer of electric current to the prime mover which furnishes the power to produce this current, there is no weaker link than the insulations employed. When the voltages used were a few hundred at most, the function of the insulation was mainly mechanical separation. With the increasing voltages and increasing complexity and magnitude of our systems of generation and distribution of electric current, the question of satisfactory insulations becomes one of paramount importance. It may be useful, therefore, to review the history of some of the more common insulations in use and consider why some have survived and some have failed. The four main constituent parts of electrical machinery are:—

Conducting material (copper)
Magnetic material (iron)
Structural material (iron, etc.)
Insulating material.

The copper, iron and structural materials comprise but a few varieties and their characteristics are relatively well known. Insulating material comprises an enormous variety and there is no material available which even approaches a satisfactory ideal and the subject, therefore, becomes a very complicated one.

The writer has always taken delight in fine mechanisms and accurate instruments and it was, therefore, with a great deal of reluctance that he undertook, nearly thirty years ago, a systematic attempt to provide insulation specifications for the apparatus manufactured by his company. He considered that he had been given a job where the main work was that of wrapping a more or less indefinite bunch of wires with rags and paper, and then doping them with messy varnish; and where it was impossible to do anything approaching fine machine or instrument work. The work was undertaken with the understanding that at the end of a year a change could be made, if desired, to something more congenial. It was soon found, however, that the subject was one of tremendous importance and of great interest; no change was requested at the end of a year and the writer has, to use a university term, "majored" in this subject ever since.

In the beginning, (and by the "beginning" is meant in 1890 or 1891) there were practically no factories devoted to the business of manufacturing insulation as such. Now, the manufacture of insulation, as a business, involves the turning out of products worth many millions of dollars yearly. Then, there was little or nothing known as to ways or means of studying the characteristics of insulation and fewer tools and instruments for carrying on such studies. Now, while we are just beginning to carry on this work with some degree of satisfaction, we have many tools, instruments and methods wholly unknown 25 or 30 years ago, which should in time give us real knowledge of a subject of vast importance to all concerned.

The present great advance in electrical development, resulting in our present systems of production, distribution and utilization of electric current, had its real beginning in the late 80's and the early 90's. At that time, the most satisfactory instruments for measuring alternating-current and alternating voltage were the electrodynamometer and the hot wire (or Cardew) voltmeter. Similarly, devices for studying the characteristics of insulation were the magneto for "ringing out" and the high resistance galvanometer for measuring insulation resistance. During his engineering course in the University the writer never heard the terms "breakdown strength" or "dielectric strength" of insulation. Curiously enough, the characteristic known as "insulation resistance", then looked upon as the most satisfactory criterion of the quality of insulation, is now one of the least used, the most variable and perhaps the least understood, although still of value in many cases in assisting in the final judgment as to the characteristics of an insulating material.

As already indicated, insulating materials and insulations were then looked upon as incidental and necessary evils rather than as a main division of the engineering work in the design of electrical apparatus. Most of the insulating materials used in the manufacture of electrical apparatus were manufactured for other purposes and merely adapted to electrical uses as they happened to apply. Varnish manufactured for other purposes was used for saturating the coating of the papers and cloths used for insulating purposes. Tapes originally intended for the millinery and dress goods trade were our insulating tapes. On one occasion samples of practically all the various types of fabrics obtainable from a large department store were tested for their adaptability as insulation.

The writer does not know who originated the idea of testing insulation for dielectric strength by means of an alternating voltage gradually increased to a sufficient amount to puncture the insulation under test. Apparatus suitable for making dielectric tests was devised by Mr. C. F. Scott and the writer, and an elaborate set of experiments undertaken under the direction of Albert Schmid in the early part of 1891. This work included the dielectric testing of all important electrical apparatus then being manufactured by the Company. In those early days there was practically no literature on the subject and every device used, every standard of test and every working tool had to be designed and constructed for the purpose.

The first testing outfit consisted of a battery of six 1000 volt transformers having their high tension windings in series and their low tension windings in multiple. By bringing out loops from one of the transformers, steps of a few hundred volts over the whole range up to 6000 volts could be obtained. With this device, much preliminary data was obtained and a great many armatures and other devices were "blown up", much to the disgust of the foremen, workmen and management, especially as it affected promised deliveries. On railway motor armatures, the original test was started at 750 volts on 500 volt motors and the old records show that approximately 25 percent of the armatures tested broke down. These breakdowns were due to the fact that the insulating cells were neither overlapped nor sealed, nor extended hardly at all beyond the ends of the iron core. When the cause of the trouble was understood, the cure was simple. Is it any wonder that the operating man felt that he, too, had his troubles in those days; when his armatures could not have been guaranteed to withstand more than 750 volts and when the lightning arrester designer complained bitterly that the armatures were better lightning arresters than he could produce, even if they would stand only one shock. At the present time, a fatality of one percent breakdowns in the testing of railway motor armatures at 3000 to 5000 volts is considered an epidemic to be looked after and remedied instantly. This early testing work resulted in an exceedingly rapid betterment of insulated structures and in a better knowledge of insulating materials. As time went on there was a tendency to increase the testing voltage and along with this increased test there was a constant decrease in the percentage of breakdowns which occurred in the finished apparatus.

There was great uncertainty as to what should constitute a dielectric test satisfactory both to the manufacturer and the user of apparatus, although as a matter of fact the user, knowing little or nothing of dielectric tests, was rarely a party to the controversy which was waged between those responsible for the tests and those responsible for the delivery of the apparatus. The tests were mainly made by the manufacturer for his own information and protection, and for the express purpose of bettering his product. Gradually, after nearly fifteen years, certain definite standards crystallized out of this type of testing and it became recognized that a dielectric test at too high a voltage might be worse than no test at all. The testing voltages finally adopted were the result of the evolution of many years of trial with continuous attempts to better the performance of the apparatus which was being put on the market. This early work was carried on almost altogether by the manufacturer so that the expense and trouble, resulting from increasing dielectric tests, breakdowns of the apparatus by over-zealous testers and the increasing cost of building the apparatus to meet the more drastic requirements, fell primarily on the manufacturer.

In the early days of the Standardization Rules of the American Institute of Electrical Engineers, a study of the miscellaneous standards then existing for dielectric tests showed that a standard of double the normal voltage of the apparatus plus 1000 volts satisfied the major part of the standards. This test was, therefore, selected as the general standard and both the experience leading up to this standard and its satisfactory application later justifies the belief that it is the right test for general use. Certain specific exceptions from this test are allowed, but it is recognized as the standard for perhaps 95 percent of all dielectric tests made on finished apparatus. It is recognized not only as a national standard but has come into international use, so that it is now generally accepted as standard throughout the world, by both producers and users of electrical apparatus.

The recognition of the influence of time of application, frequency and wave shape of the current used, and the temperature of the insulation had gradually become established during the years leading up to the standardization above referred to and as a consequence the A. I. E. E. standards specify the time of application, frequency and wave shape and generally the temperature at which tests shall be made.

INSULATING VARNISH

One of the earliest needs in the line of material suitably adapted to the insulation of electrical apparatus was that of insulating varnish. On strongly urging this need to his superiors, the writer was given a letter of introduction to a young chemist, who was trying to establish himself in the coach varnish business, with "carte blanche" to work with him with a view of developing a suitable insulating varnish. For approximately two years, trial after trial and test after test were made, the chemist furnishing the samples of varnish and the speaker doing the testing work. Finally a varnish was produced which was adjudged suitable for general use. The fundamental requirements as set for this varnish were:—

> That it should be moisture resisting.
> That it should have high insulating value.
> That it should be insoluble in lubricating or transformer oil.
> That it should give a good finish, i. e., suitable for either dipping or applying by a brush.

The varnish finally adopted was a baking varnish with what is known as a linseed oil base and a benzine thinner. The success of the work can be judged by the fact that this varnish for many years was the standard with many manufacturers and users, and was largely used throughout both this country and Europe.

For nearly 30 years, the man who started out to produce coach varnishes has headed the pioneer firm devoted exclusively to the production of insulating varnishes. Many others have arisen and many improvements have been made but, in general, the type of varnish for insulating purposes has been but little changed to this time. Many attempts have been made to produce an air-drying varnish that would be equally satisfactory, everything considered, as the baking varnishes originally adopted and since generally used. So far these attemps have not been more than moderately successful.

MICA

The story of mica is of great interest due to the fact that for some purposes mica is an ideal insulation and due to the constantly decreased sizes of mica available as the use has grown. In the early days of the so-called high voltage generator (i. e., alternators giving 1000 to 1200 volts), it was not uncommon to use sheets of pure mica 10 to 12 inches square and commutator segments were regularly punched from large sheets. The available supply has been so reduced that such sheets are now looked upon as curiosities, while the use of mica has grown many hundred-fold. Taking into account the present day designs of electrical machinery and the characteristics desired in the mica used, the built-up mica of today made from small pieces is much more satisfactory on the whole than the large mica available 25 years ago. On one occasion a whole line of railway motors had to have their commutators completely rebuilt, although the finest mica available was used between the commutator segments, this being an amber mica punched from large sheets. The difficulty was that the mica so built up was so hard that the copper wore down faster than the mica, leaving projecting mica which kept the brush above the copper, resulting in a blackened and ruined commutator. The difficulty in this particular case was overcome by splitting the mica into very thin sheets, not over 0.001 or 0.002 inches, and building it up to the proper thickness.

The mica now available would have been considered unusable 25 years ago. On account of the constantly reduced size, machine methods have had to be developed for building mica which, fortunately, have brought the desired result, even under the otherwise adverse conditions. Mica, like other insulating materials, is a good heat insulator, particularly when split very thin and built up with no bond. Together with asbestos, however, it provides the only real heat-proof insulation available at the present time. By "heat-proof" is meant insulation which will withstand temperatures well above the boiling point of water. The Niagara Falls generators installed in 1894 or 1895, insulated with mica, are perhaps the best examples extant of insulating structures running at high temperatures over a long period, although designed to operate at moderate temperatures. It has been found in the last few years that these machines have run for long periods of time at actual temperatures at the hottest spot of 200 degrees C. Mica will, therefore, undoubtedly continue as the material par excellence for commutator work and for insulating windings where such high temperatures prevail.

TRANSFORMER OIL

One of the most interesting developments in insulation has been that of transformer oil. When the Pomona 10 000 volt transmission was decided upon, in the latter part of 1891, it became necessary to investigate the subject of oils suitable for transformer insulation. A long series of tests was made and practically every type of oil then available in quantity—animal, vegetable and mineral—was tried out. Judgment was formed mainly on the result of the new dielectric test which had recently been largely adopted for the judging of other insulating materials. Special testing devices suitable for the testing of oil had to be devised and the increased voltages required to get satisfactory tests made it necessary greatly to extend the range of the testing apparatus hitherto available.

Early in the tests in connection with the Pomona transformers, it was decided that mineral oils would probably be the most satisfactory, both on account of their availability, cheapness and their superior insulating qualities. Special attention was, therefore, devoted to mineral oils and tests were made covering every available class from the heaviest cylinder oils to the benzines. The final selection for the Pomona plant was that of a commercial grade of oil known as "Diamond Paraffine". Later developments indicated the desirability of using a somewhat lighter oil and a commercial grade of heavy burning oil known as 300 degrees Mineral Seal was adopted. About this time the Underwriting interests became alarmed at the use of an oil having so low a flash test, particularly in view of the type of containers used for transformers, and the type of transformer station construction then in use. A further investigation led to the adoption of a specification for transformer oil requiring transformer oil to have a much higher flash test than the Mineral Seal and to be obtained by fractional distillation of crude petroleum without subsequent chemical treatment. Coincident with this development, transformers of larger size and the scheme of water-cooling of transformers came into use.

Trouble soon developed in transformers using this heavier oil, due to the formation of a deposit which clogged up the cooling passages in the transformer and which settled on the cold parts of the transformer case and particularly on the cooling coils. This deposit, while equally as good an insulator as the oil itself, seriously interfered with the cooling of the transformer, and numerous burnouts resulted. This led to a further intensive study lasting for several years in the laboratory and in the field, with a view of developing an oil which would have the high flash point desired by the Underwriters, the high insulating quality required for transformer work and which would be free from sludging. Such an oil was finally developed and its satisfactory character has been demonstrated by its use to the extent of many millions of gallons.

It is interesting to note that the earlier specification to the effect that transformer oil must be obtained by fractional distillation without further chemical treatment (the object of this specification being to eliminate all chemicals from the oil) had to be changed for the new oil, for although it is not known definitely just what causes sludging, it is known that chemical treatment to remove color and thorough filtration will very greatly reduce sludging.

Later developments brought about the present type of transformer case and the present type of transformer station, so that the danger of fire from the lighter oil has been very largely, if not entirely, eliminated. Difficulty with the higher flash oils, due to their greater viscosity and consequently their poorer cooling characteristics, led to further development, resulting in the almost universal adoption of an oil for transformer insulation having a flash point considerably below those formerly considered necessary on account of the fire hazard. Such an oil will take up and hold less moisture, has in general a higher insulating value and is a much better cooling medium at relatively low temperatures than higher flash point oil.

It should be observed, however, that the viscosity of all the oils, now considered within the range satisfactory for transformer insulation, is approximately the same at the maximum temperature at which transformers are supposed to operate. Consequently, there is little difference in the rise in temperature at maximum ambient and operating temperatures of transformers using low viscosity or high viscosity oil. There may be, however, a very considerable difference at low ambient temperature or at partial loads and this fact has been so little understood by operators in general that transformers tested at a low air temperature might be rejected on account of exceeding the temperature rise guaranteed.

Many attempts have been made to secure an insulating liquid which would not be combustible and these attempts have mainly taken the form of the production of a material in which the hydrogen of the hydrocarbon has been replaced by chlorine or a similar substance. Tetrachloride of carbon is satisfactory from some standpoints as an insulating liquid to replace transformer oil, but on account of the low temperature at which it boils and on account of the physiological effect of the vapor on operatives, it has never made much headway as a transformer insulation. The production of such an insulating liquid would make a very notable advance in the science of transformer engineering.

MOLDED INSULATION

Molded insulation, while of relatively less importance than some others which have already been mentioned, nevertheless plays a very important part in the construction of electrical apparatus. By molded insulation is here meant those products which are molded into the desired form, using compounds and mixtures under pressure and usually with heat. They are of three general classes:—

1- Those which depend for their molding quality on the melting of the contained binder and then set to shape in the mold by cooling.

2—Those which are formed cold from mixtures containing a material like cement and which get their final characteristics by setting or chemical action.

3—Those which are formed by melting or softening the compound and then changing to final state by chemical action brought on by heating the object either in the mold or subsequently, such as vulcanizing or bakelizing.

There are also innumerable combinations of the above, as well as other mixtures, etc., not coming under these classifications.

The story of molded insulation would make a book in itself, so that all that will be done here will be to say something of the classes which have been used and those in general use today. The earliest in the field was the rubber compound, either in the form of hard or semihard rubber, and these were closely followed by the rubber substitutes. The variety and quantity of the latter are legion, as almost every conceivable material has been used for the purpose. In fact it has often seemed that when material of a gummy nature was produced which had no visible use, it was proposed as a new and wonderful molding product. The receipt of one letter is recalled where the writer frankly stated that the sample he was sending apparently had no other use whatever, therefore it must be a good material for making molded insulation. There has been a gradual abandonment of molded rubber for most uses because of its relatively poor mechanical qualities and its low heat resistance. The same difficulty is experienced with many of the rubber substitutes which are used as a binder, such materials as asphalt, coal tar pitch and various vegetable gums such as shellac. Where the temperatures are very moderate and the mechanical characteristics not exacting, many of the rubber substitutes still serve their purpose admirably. The advent of the synthetic resins, such as bakelite, brought on a new era in molded insulation on account of the better mechanical and heat-resisting characteristics of such molded materials. These desirable characteristics are, however, offset to a certain extent by somewhat lower insulating values than are found in the best grades of rubber and rubber substitutes.

Like all other insulators, therefore, the actual molded materials are generally a compromise between the theoretically desirable characteristics and those which can be obtained in practice. On account of the wide variety of grades and forms of molded insulation, there has been no generally recognized method of judging the characteristics of a molded material, but during the last few years such an attempt has been made and in tentative form the specification for making such tests may be found in the Proceedings of the American Society for Testing Materials.

GLASS AND PORCELAIN INSULATORS

Another phase of the insulation question which is of paramount importance to the operating companies is that of line insulators. Prior to 1890 or 1891 the general method of judging the insulation was that of measuring insulation resistance and this was of very considerable importance in telephone and telegraph installations. It had been found that a line using glass insulators gave relatively low insulation resistance during adverse weather conditions and, as it was intended to use glass insulators for the Pomona transmission, the original plans included a scheme for having an annular oil cup around the insulator pin in such a way that the path over the surface of the insulator from the line wire to the pin would be broken up by having interposed an oil surface. High voltage tests on insulators of this type and on those without the oil cup, gave evidence that the oil cup was not necessary for high voltage transmission and that it would be difficult to maintain.

The rapid rise of the porcelain insulator in place of the glass insulator has been due to its better mechanical characteristics, that is, greater mechanical strength and lower temperature coefficient. The Missouri River Power Company's transmission (at first 50 000 volts and later raised to 70 000) is the highest ever attempted with glass insulators. Here the main difficulty was not with the dielectric value or the insulation resistance, but with the mechanical characteristics. Glass has some distinct advantages over porcelain but these have not been sufficient to allow it to become a standard for high voltage transmission. These advantages are mainly those of its relative homogeneity and its transparency, allowing easy inspection to be made for faults and its high dielectric strength. A low temperature coefficient glass may yet be produced which would find a place in high voltage transmission.

The development of the porcelain insulator has been mainly that of form and method of mounting rather than in the ceramic art, although in later years this latter phase has received serious consideration, particularly in view of the so-called deterioration of insulators in service. The design of porcelain insulators for many years was dominated mainly by the idea of securing as large an amount of arcing distance and dry surface from the line wire to the pin as possible. In recent years, through the application of scientific principles, it has been possible to re-arrange the electrostatic flux, both in the air and in the porcelain itself, and provide surfaces corresponding to the flow lines and equipotential surfaces of the electrostatic field. These considerations have very largely changed the dominating designs and have already produced a very superior and entirely practical type of insulator. The advent of the suspension insulator was inevitable and came about from the fact that the sizes of pin insulators practical with present ceramic methods and pin construction are reached for line voltages of from 66 000 to 88 000 volts.

Many attempts have been made to find substitutes for the porcelain insulator for high voltage transmission, but the porcelain insulator still dominates the field, on account of its characteristics averaging up better than those of any competitor. It would be wholly unsafe to predict what may be in store in the future but with the probable advent of super-power lines of 220 000 volts and possibly higher, the line insulator question must receive the most serious consideration.

SHEET INSULATION

The fabrics and paper, or sheet insulation, constitute one of the important classes of insulations. There has been little change in the types of fabrics and papers available during the last 25 years. A large amount of special fabric and paper has been manufactured specifically for insulation purposes but such modifications as have been made have been in the main for mechanical purposes rather than on account of the insulation. A notable exception is in the heavy paper or so-called fullerboard used for high voltage transformer insulation where the specifications have changed from requiring a dense material to one requiring a fairly soft and porous material. This is found desirable, due to the very considerably decreased dielectric losses in the porous material when thoroughly saturated with transformer oil. There has, however, been great advance in the art of manufacturing so-called treated papers and cloths, and also the chemically prepared papers and impregnated sheet material. These developments have been due more to the quality of the varnishes and impregnating materials than to any improvements in the sheet material with which these varnishes and impregnating materials are used. At the present time little sheet material or fabrics are used for insulating purposes which are not saturated and coated with varnish or similar material. This is true when such materials are applied in the "dry" state to windings as these windings are usually "dipped" afterward. Such papers, boards and fabrics constitute a very large portion of the insulation used and are, therefore, a most important part of the subject. The use of synthetic resins as impregnating material forms the only notable advance in these materials for many years and this can be considered an addition to rather than a substitute for those already available.

THE ENEMIES OF INSULATION

The arch enemies of insulation are moisture and temperature. The recognition of the extremely important part which moisture plays in connection with insulation troubles came quite gradually. This was perhaps to be expected as the development of the art has been gradual and the ways and means of definitely determining the cause of insulation troubles have also been somewhat slow in development. Furthermore, the importance of the influence of extremely small amounts of moisture has naturally grown with the increase in voltages used.

The influence of moisture in greatly increasing the dielectric losses was definitely brought out and the results were published in a paper before the American Institute of Electrical Engineers in 1902. At the time of the construction of the Ontario Power Company's 60 000 volt transmission lines, the stage had been reached when it was considered advisable to vacuum dry complete transformers before immersing them in oil. Equipment for this purpose was not available for transformers of the size used by the Ontario Power Co. and it was therefore decided to make the transformer tank itself the vacuum tank and provide means for vacuum drying the transformers after they were placed in the tanks at the point of installation. After drying for a week or 10 days, following the course of the drying by measuring insulation resistance of the transformers until this was considered satisfactory, oil was admitted to the first transformer while still under vacuum. As a final precaution a sample of oil was drawn from the bottom of the tank only to find that it was about 98 percent water. Investigation of a second transformer into which the oil had not been admitted resulted in the discovery of 6 or 7 gallons of water in the bottom of the transformer tank, although the transformer itself was undoubtedly satisfactorily dried by the vacuum process. The water undoubtedly came partly from the transformer coils, partly from the laminated iron and partly from the air which was inevitably drawn into the transformer tank on account of the impossibility of making the tank absolutely vacuum tight. This moisture condensing on the cooler top and sides of the tank, collected at the bottom. The cure was very simple and consisted in a double valve arrangement with a small tank between, allowing the condensed water to be drawn off as the drying proceeded. This incident shows the very large quantities of water which could be collected under the circumstances described and indicates that apparatus, not satisfactorily protected by a moisture-proof coating or by immersion in oil, requires special precautions in installation and starting. Later studies have indicated that moisture in extremely minute amounts may play a very important part in impairing insulation where the requirements are severe, as it may increase the dielectric losses and lower the insulation resistance and the dielectric value.

It must be evident from the preceding that a bone-dry condition is desirable for practically all insulation and that a certain amount of temperature is necessary as a rule in order to bring about this bone-dry condition. The matter of temperature becomes important from the standpoint of causing trouble in insulation only when certain limiting temperatures are passed and the question of what should constitute the maximum allowable temperature for the various types of insulation has been the subject of an enormous amount of experimentation and discussion. It is usually the vital factor in determining the rating of electrical apparatus.

Practically no organic materials will withstand continuous temperatures very much in excess of the boiling of water without deterioration. Such materials vary among themselves to a certain extent in the temperature they will withstand without deterioration, but this range is not so great. At about the limiting value, mechanical deterioration of the material rather than deterioration of its electrical and insulating characteristics is the determining factor. All such materials deteriorate rapidly when temperatures approaching what might be called the scorching point are reached. The figure finally accepted by the Standardization Committee of the American Institute of Electrical Engineers as the maximum allowable for continuous temperature for organic materials is 105 degrees C. and even in this case it is required that fibrous materials be protected by having the fibers coated with varnish or treated with impregnating materials. The varnish gums and impregnating materials, and particularly those obtained from asphalts, mineral oils and coal tar products, will withstand somewhat higher temperatures than the fibrous materials, such as cotton, linen, etc. They are also less readily oxidizable and therefore provide a certain amount of protection for fibrous materials at these high temperatures.

Either moisture or temperature may cause deterioration but under operating conditions the combination of the two makes the most difficult condition to meet.

INSULATIONS OF THE FUTURE

In order to see how far insulations are from perfection, it is only necessary to outline some of the characteristics for a perfect insulation. The theoretically desirable insulation specification would probably call for two materials—one a solid and the other a liquid. In the solids there might be brass or copper as the base, requiring that in addition to the physical characteristics which they now have, they should be perfect insulators. These materials would be capable of being rolled, drawn, spun and in fact worked as we now work the most ductile metals. Electrical insulating qualities equal to mica, would be required along with the heat conductivity of copper. It might even be desirable to be able to dissolve the material, like shellac, and apply it in thin coats and then have it return to its metallic characteristics. It would be very easy to outline numerous other desirable characteristics but for the present purpose the above is probably sufficient.

For liquid insulators the requirements would be that it be non-burnable, that its boiling point be very high, that its power of carrying heat be at least equal to that of water, and in fact water might be taken as the base on which to build the desirable characteristics.

It may seem futile to take time to even outline such desirable characteristics of insulating materials, since there is little or no hope at the present time of attaining these characteristics. It does serve to show, however, how far we are from the ideal and as considerable advances have been made in the characteristics of insulating materials in the past we should have some such idea to guide in our future work. We must work with the materials at hand and improve their characteristics as far as possible in line with our ideals. Instead of working with the two or three desirable insulations, we must work with a vast number, each of which has its peculiar limitations. We may well question, from our present knowledge of the art, what advances are possible. We certainly should expect to make advances in practically every class which has been described and in many other classes.

The advances in the art of making synthetic gums and synthetic rubbers lead to the belief that further advances along these lines are probable and it is hoped that new materials will be developed which will be much less subject to deterioration by heat and will provide more satisfactory moisture-proofing than the present materials.

There are already a few liquid insulators which are fireproof, such as tetrachloride of carbon, and a non-burnable liquid may be developed which will be a satisfactory substitute for transformer oil. At present, asbestos is practically the only non-burnable fiber which can be spun and woven, but it lacks very much of being an ideal material, both from the insulation standpoint and the mechanical standpoint. A substitute for asbestos with more desirable characteristics may be found in the future. Along with this, non-burnable insulating coatings or varnishes may be produced. Of necessity, something better than the present line insulator must be developed for extremely high voltage work, either through advances in the ceramic art or the production of a totally new material or combination for this purpose.

The demands upon insulating materials for the generator, the motor, the transformer and the transmission line are varied and exacting. It should resist mechanical deterioration and chemical change under the ordinarily destructive influences of high temperature and of moisture and weather; it should resist breakdown due to mechanical stresses and electrical stresses, both under normal operation and the momentary extremes due to short-circuit on the one hand or voltage peaks on the other. It should combine in one material the best qualities of a dozen different materials and even then it would be short of the ideal.

Electrical Characteristics of Transmission Circuits-IX

Performance of Long Transmission Lines
(Rigorous Convergent Series Solution)

Wm. Nesbit

THE APPROXIMATE electrical performance of overhead circuits having a length not exceeding 300 miles, may readily be determined by the use of the Wilkinson Charts for determining the values of the auxiliary constants, supplemented by vector diagrams representing the current and voltages of the circuits. In important cases, as a final check upon the values obtained by the simple graphical solution, a mathematical solution yielding rigorous results should be made. If the circuit is more than 300 miles long, a mathematical solution yielding rigorous values will be required for determining the correct values of at least the auxiliary constants.

FORMS OF RIGOROUS SOLUTIONS

The most direct method for determining mathematically the exact performance of circuits of great electrical length is by the employment of hyperbolic functions, and the fundamental equations are usually expressed in such terms. Many engineers have a general aversion to the use of mathematical expressions employing hyperbolic functions. One reason for this is that the older engineers attended college before the hyperbolic theory as applied to transmission circuits had been developed, and tables of such functions were not at that time available.

In 1893 Dr. A. E. Kennelly introduced vector arithmetic into alternating-current computation for the first time.* Although real hyperbolic functions had well recognized uses in applied science, it was in 1894** that he, for the first time, suggested and illustrated the application of vector hyperbolic functions to the determinations of the electrical performance of transmission circuits. Since that time Dr. Kennelly has been a most persistent advocate of the employment of these functions in electrical engineering problems. To advance their use, he has calculated and published numerous tables and charts of such functions. Such tables were, until recently, incomplete and the result was that it was necessary, in using these tables, to interpolate values, thus introducing complications and inaccuracies into the calculations.

Tables of hyperbolic functions and charts are now sufficiently extensive and complete for accurate work. The universities quite generally are encouraging instruction of students in the hyperbolic theory. It is therefore to be expected that, in the future, the employment of hyperbolic functions for the solution of long transmission lines will come into general use.

The fundamental hyperbolic equations expressing the electrical behavior of transmission circuits may be expressed in the form of convergent series and, in such form have, in some cases, certain advantages over the hyperbolic form. The convergent series form of solution does not require the employment of tables or charts of hyperbolic functions, whereas hyperbolic forms of solutions do require such tables or charts. If, therefore, such tables or charts are not available, hyperbolic solutions cannot be employed.

While the amount of arithmetical work involved is considerable, any degree of accuracy may readily be obtained by the convergent series solution by working out the terms for the auxiliary constants until they become too small to have any effect upon the results. This can also be done with hyperbolic functions, but exact interpolation of such functions from tabular values, may be considered more difficult than the working out of an extra term or two in the convergent series form of solution. The above remarks apply to cases where an unusual degree of accuracy is required. Later will be included a tabulation of the performance of 64 different electrical circuits, as determined by a rigorous, and also by eight different approximate methods of calculation. As the rigorous values are taken as 100 percent correct, in determining the percent error by the approximate methods, it was important that the so called "rigorous" values be exact. To make them so, it was found convenient to employ the convergent series form of solution for these particular problems, covering circuits up to 500 miles long and potentials up to 200 000 volts. For the calculation of the performance of practical power transmission circuits, tables of hyperbolic functions are now sufficiently complete to yield results well within the errors due to variation in the assumed linear constants of the circuits from their actual values.

The employment of convergent series requires a working knowledge of complex quantities only, whereas the employment of hyperbolic functions in addition leads into hyperbolic trigonometry. As literature pertaining to the hyperbolic theory becomes more generally available, and as the younger engineers take up active engineering work, the hyperbolic theory will become more generally used.

For the purpose of providing a choice of rigorous methods, both convergent series and two forms of hy-

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Trans. Am. Inst. Elec. Engrs., Vol. X, page 175 "Impedance."

***"Electrical World"*, Vol. XXIII, No. 1, page 17, January 1894, "The Fall of Pressure in Long-Distance Alternating-Current Conductors."

perbolic solutions are given. The numerical values employed in these solutions have been carried to what may appear as an unnecessary degree of precision. The reason for this is to demonstrate the fact that all of these rigorous solutions yield the same results. For practical problems less accuracy would be essential, thus reducing the amount of arithmetical work.

Before taking up the rigorous solutions, it has been thought desirable to review the rules regarding the use of complex quantities and vector operations.

COMPLEX QUANTITIES

The calculation of the auxiliary constants of the circuit by convergent series, and the further calculation of the electrical performance of the circuit, involve the use of complex numbers, that is, numbers containing j terms. Thus $A = a_1 + ja_2$ is a complex quantity. To the beginner, expressions containing j terms may seem difficult to understand. It cannot be made too emphatic that the rules governing the use of such terms are so simple (embodying only the simple rules of algebra) that the beginner will shortly be surprised with the ease at which complex quantities are handled.

j Terms—In the complex notation $Z = X + jY$, the prefix j indicates that the value Y is measured along the axis perpendicular to that of X, or what is called the imaginary axis. There need be no significance attached to the symbol j other than that of a mere distinguishing mark, to designate a distance above or below the reference axis in the vector diagram. However, great use is made of a further assigned significance. It has a numerical significance in the form of $j = \sqrt{-1}$ which enables all formal algebraic operations, multiplication, addition, extraction of roots, etc. incident to computation involving complex quantities, to be carried out rigorously. This numerical designation for j does not prevent its use as a designating symbol for the vertical direction in the vector diagram.*

PLANE VECTORS

Alternating voltages and currents which vary according to the sine or cosine law, may be represented graphically by directed straight lines, called plane vectors. The length of the vector represents the effective value of the alternating quantity, while the position of the vector with respect to a selected reference vector, base or axis, gives the phase displacement. The line *OP*, of Fig. 29, represents a plane vector inclined at an angle of 33° 41′ with the base *OS* (the axis of reference). The length of the line *OP* is a measure, to some assumed scale, of the effective value of the voltage or current, while the angle *SOP* gives the phase displacement.

Counter-clockwise rotation is considered positive. Thus, in Fig. 29, if the line *OS* represents the instantaneous direction of the current and the line *OP* that of the voltage at the same instant, the current is represented as lagging behind the voltage by the angle 33° 41′. By means of vectors the relative phase position and value of either currents or e.m.f.'s can be represented in the same manner as forces in mechanics.

The position of *P*, with respect to *O*, is usually defined in terms of rectangular or polar co-ordinates. In rectangular co-ordinates there are two fixed mutually perpendicular axes, —*XOX* and —*YOY* (Fig. 31) in the plane of reference. The former, —*XOX*, is called the real axis, or axis of real quantities. The latter, —YOY, is called the imaginary axis, or axis of imaginary quantities. The qualifying adjective "imaginary" does not mean that there is anything indeterminate or fictitious about this axis. The perpendicular projections of *P-1* (Fig. 31) on the *X* and *Y* axes are respectively the real component *X*, and the imaginary component *Y*.

The magnitude and sign of the rectangular components *X* and *Y* completely determine the position of the vector *OP*. Positive is indicated to right and upward, negative to the left and downward as indicated in Fig. 30. Thus, if *X* and *Y* are both positive, *OP* lies in the first quadrant. If *X* and *Y* are both negative, *OP* lies in the third quadrant. If *X* is — and *Y* is +, *OP* lies in the second quadrant. If *X* is + and *Y* is —, *OP* lies in the fourth quadrant. Any plane vector may be completely specified by its real and imaginary components *X* and *Y*. Thus, beneath Fig. 31, is a table in which the point *P* is located in the plane by co-ordinates for all quadrants.

From Fig. 30 it is evident that, mathematically, the quadrature numbers are just as real as the others. The quadrature numbers represent the vertical, and the ordinary numbers the horizontal directions.

VECTOR OPERATIONS

In general, in the handling of complex numbers involving j terms, the simple rules of algebra are followed. In Fig. 32 two vector quantities are shown. Vector *A* has a magnitude of 5 units and is inclined in the positive or leading direction at an angle of 36° 52′ with the horizontal reference vector, and vector *B* has a magnitude of 4.47 units, and is inclined in the positive or leading direction at an angle of 63° 26′ with the reference vector. These vector quantities are expressed in rectangular co-ordinates as $A = 4 + j3$, $B = +2 + j4$ or in polar co-ordinates as $A = 5\ /36^\circ\ 52'$, $B = 4.47\ /63^\circ\ 26'$. The prefix j simply means that the number following it is measured along the vertical or *Y* axis. The dot under the vector designation indicates that *A* is expressed as a complex number, so that the absolute value of *A* would be $\sqrt{(4)^2 + (3)^2} = 5$ and of $B = \sqrt{(2)^2 + (4)^2} = 4.47$. The absolute value of a complex number is called its "size"; while the angle is called its "slope".

In order to illustrate the handling of complex quantities, the various operations of addition, subtraction, multiplication, division, evolution and involution of the vectors *A* and *B* in Fig. 32, will be performed.

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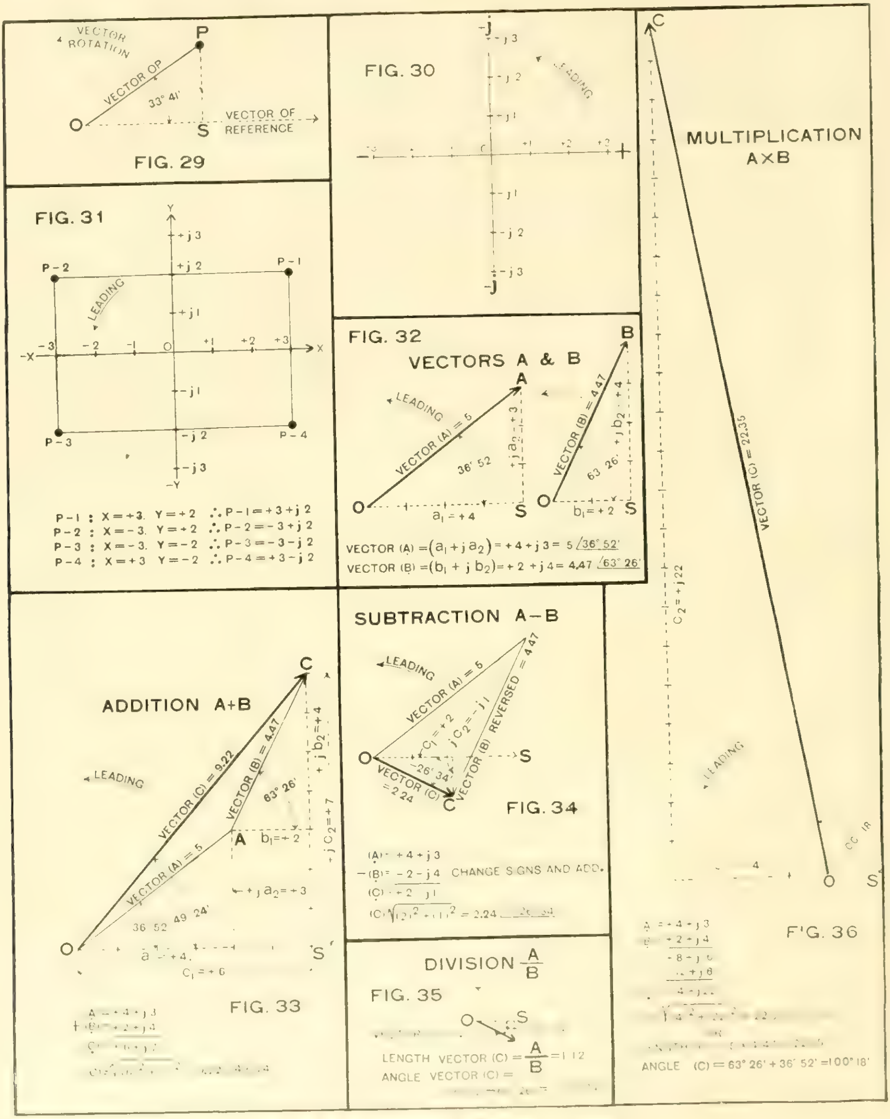
*For an extended explanation of j terms, reference is made to Dr. Charles P. Steinmetz's "Enginering Mathematics", and Dr. A. E. Kennelly's "Artificial Electric Lines."



Figs. 29 to 36—[illegible]

Addition—Fig. 33 illustrates the addition of these vectors expressed in rectangular co-ordinates. The resulting vector will have as its real component, the algebraic sum of the reals, and as its imaginary component, the algebraic sum of the imaginaries. Thus:

$$A = 4 + j3$$
$$B = 2 + j4$$
$$A + B = C = 6 + j7$$
$$C = \sqrt{6^2 + 7^2} = 9.22 \text{ absolute.}$$

The resulting vector has, therefore, a size of 9.22 units and is inclined in the forward direction at a slope of 49° 24′ with reference to the initial line, *OS*.

Subtraction—Fig. 34 illustrates the subtraction *A* − *B*. This is simply addition after the signs of both of the components of the vector to be subtracted have been reversed. Thus,—

$$A = 4 + j3$$
$$B = 2 + j4$$
$$A - B = C = 2 - j1$$
$$C = \sqrt{2^2 + 1^2} = 2.24 \text{ absolute.}$$

The resulting vector C has therefore a size of 2.24 units and a slope of — 26° 34′. In polar co-ordinates, $C = 2.24 \overline{/-26° 34'}$.

Division—To divide one plane vector by another, divide their sizes and subtract their slopes, Fig. 35. Thus,—

$$\text{Absolute value of } C = \frac{5}{4.47} = 1.12$$

Angle of inclination of C = 36° 52′ — 63° 26′ = — 26° 34′ in the negative direction. In polar co-ordinates $C = 1.12 \overline{/-26° 34'}$.

Multiplication—Fig. 36 illustrates the multiplication of the vectors A and B. Here the rules of algebra

$$A = 4 + j\,3$$
$$B = 2 + j\,4$$
$$8 + j\,6$$
$$-12 + j\,16$$
$$A \times B = C = -4 + j\,22 = 22.35 \text{ absolute}$$

The resulting vector C has therefore a size of 22.35 units and is inclined in the positive direction at an angle of 100° 18′ to the vector of reference. The polar expression is $C = 22.35 \underline{/100° 18'}$

The magnitude and position of the product may be also determined by multiplying the sizes of the vectors and adding their slopes. Thus:—

Size of $C = 5 \times 4.47 = 22.35$ (as above)
Slope of $C = 63° 26' + 36° 52' = 100° 18'$.

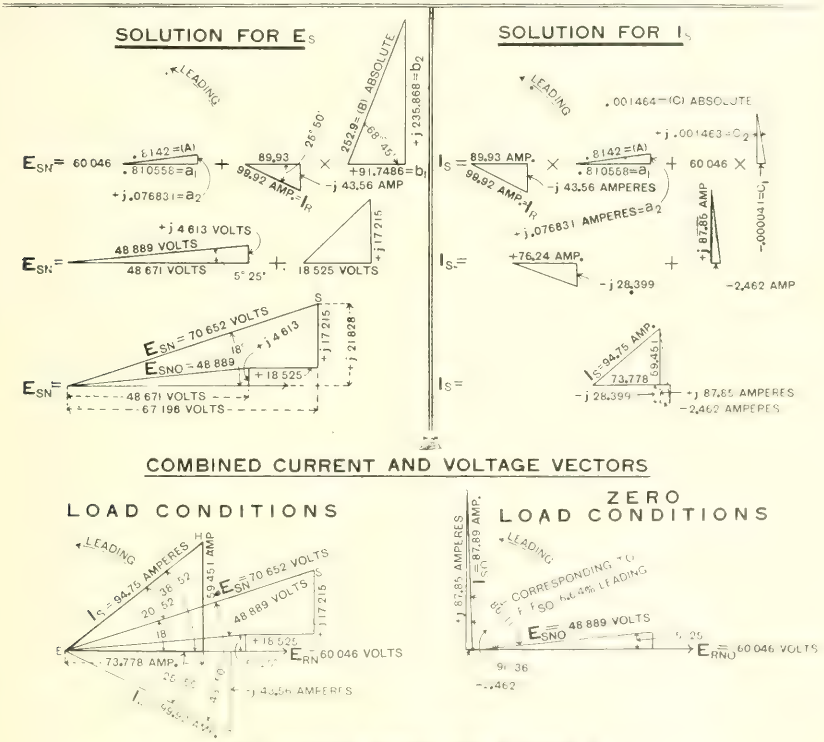


Fig. 37 [illegible]
Illustrating [illegible] calculation [illegible] performance [illegible]

also apply, except that when two j terms are multiplied signs are assigned opposite to those which would be used in the ordinary solution of an algebraic problem. This is for the reason that,—

$$j = \sqrt{-1}$$
$$\text{hence, } j^2 = -1$$

Hence where j^2 occurs it is replaced by its value —1 and therefore,—

$$-j \times j = +1$$
$$j^3 = -j$$
$$j^4 = +1$$
$$j^5 = +j, \text{ etc.}$$

Thus, to get the product of A and B:

Involution—Involution is multiple multiplication. To obtain the power of a plane vector, find the power of the polar value and multiply the angle by the power to which the vector is to be raised. Thus,—vector $A =$ [illegible] 36° 52′ [illegible] 73° 44′ [illegible] 25 $\underline{/73° 44'}$.

Evolution—To find the root of a polar plane vector, find the root of the polar value and then divide the slope by the root desired. Thus vector $A = 5 \underline{/36° 52'}$; and $\sqrt{A} = \sqrt{5 \underline{/36° 52'}} = 2.236 \underline{/18° 26'}$

SOLUTION BY CONVERGENT SERIES

The hyperbolic formula for determining the operating characteristics of a transmission circuit in which exact account is taken of all the electric properties of the circuit is frequently expressed in the following form,—

$$E_s = E_r \cosh Vl + I_r U \sinh Vl \ldots\ldots (49)$$

$$I_s = I_r \cosh Vl + E_r \frac{1}{U} \sinh Vl \ldots\ldots (50)$$

Where,—

$$Vl = \sqrt{ZY} \text{ and } U = \sqrt{\frac{Z}{Y}}$$

These formulas may therefore be expressed,—

$$E_s = E_r \cosh \sqrt{ZY} + I_r \sqrt{\frac{Z}{Y}} \sinh \sqrt{ZY} \ldots\ldots (51)$$

$$I_s = I_r \cosh \sqrt{ZY} + E_r \frac{1}{\sqrt{\frac{Z}{Y}}} \sinh \sqrt{ZY} \ldots\ldots (52)$$

Since $\sqrt{ZY}$ is complex, the hyperbolic functions of complex quantities are required in solving these equations.

In the above formulas, expressed in hyperbolic language, the three auxiliary constants A, B and C which take into account the "distributed" nature of the circuit are represented by the quantities,—

$$A = \operatorname{Cosh} \sqrt{ZY} = \cosh Vl \ldots\ldots (53)$$

$$B = \sqrt{\frac{Z}{Y}} \sinh \sqrt{ZY} = U \sinh Vl \ldots\ldots (54)$$

$$C = \frac{1}{\sqrt{\frac{Z}{Y}}} \sinh \sqrt{ZY} = \frac{1}{U} \sinh Vl \ldots\ldots (55)$$

Equations (51) and (52) above may therefore be expressed in terms of the auxiliary constants, A, B and C, as follows:—

$$E_s = E_r A + I_r B \ldots\ldots (56)$$

$$I_s = I_r A + E_r C \ldots\ldots (57)$$

$$\text{or } E_r = E_s A - I_s B \ldots\ldots (58)$$

$$I_r = I_s A - E_s C \ldots\ldots (59)$$

These three auxiliary constants may be calculated by convergent series as follows:—

$$A = \left[1 + \frac{YZ}{2} + \frac{Y^2Z^2}{24} + \frac{Y^3Z^3}{720} + \frac{Y^4Z^4}{40320} + \ldots\right] \ldots\ldots$$

$$B = Z\left[1 + \frac{YZ}{6} + \frac{Y^2Z^2}{120} + \frac{Y^3Z^3}{5040} + \ldots \&c.\right] \ldots (61)$$

$$C = Y\left[1 + \frac{YZ}{6} + \frac{Y^2Z^2}{120} + \frac{Y^3Z^3}{5040} + \ldots\right] \ldots$$

The above series are simply expressions for the auxiliary constants as previously stated. These constants are functions of the physical properties of the circuit and of the frequency only, and not of the voltage or the current. After the values for the auxiliary constants have been calculated for a given circuit and frequency their numerical values may be applied directly to any numerical values of E and I for which a solution is desired. From this point on, the performance of the circuit may be determined either by the graphical method previously described or by mathematical calculation.

Any degree of accuracy may be obtained by the use of convergent series for determining the auxiliary constants, by simply using a sufficient number of terms in the series. The rapidity of convergence of these series is dependent upon the value of the argument ZY and thus upon the square of the length of the circuit and frequency, and also, to a lesser extent upon the product of total circuit conductance and total circuit resistance.

As far as calculations based upon the more or less uncertain values of the fundamental constants of the circuit are concerned, the use of three terms in the series expression yields results in a 300 mile circuit which are sufficiently close to the exact values as given by the use of hyperbolic functions (infinite number of terms). In the case of shorter circuits two terms will give a high degree of accuracy. The number of terms necessary will be determined while doing the work, for it is usual to figure out the terms of the series until they become too small to be considered when added to $\frac{YZ}{2}$ or $\frac{YZ}{6}$.

In Table N are given values for the auxiliary constants (expressed in rectangular co-ordinates) illustrating the convergence of the series for a 300 mile, 60 cycle circuit (Problem X), the complete calculation of which will follow.

Table N shows that even for a 60 cycle, 300 mile circuit, three terms give sufficiently accurate results for determining constant A, whereas two terms are sufficient for determining constants B and C. This is on account of the slower convergence of the hyperbolic cosine series.

TABLE N—CONVERGENT SERIES TERMS FOR PROBLEM X.

No. of Terms	Constant A	Constant B	Constant C
1	1.000000 + j 0.000000	105 + j 240	0 + j 0.001563
2	+ 0.805407 + j 0.082057	+ 91.3788 + j 235.7211	− 0.000043 + j 0.001462
3	+ 0.810596 + j 0.076735	+ 91.7527 + j 235.8678	− 0.000041 + j 0.001463
4	+ 0.810558 + j 0.076832	+ 91.7486 + j 235.8680	− 0.000041 + j 0.001463
Infinite	+ 0.810558 + j 0.076831	+ 91.7486 + j 235.8680	− 0.000041 + j 0.001463

CALCULATION FOR THE AUXILIARY CONSTANTS BY CONVERGENT SERIES

The form of solution and procedure indicated in Chart XI for the calculation of the auxiliary constants by convergent series is suggested as being complete and easy to follow.

First the physical characteristics of the circuit and the frequency are stated. These are the only features having any bearing upon the value of the auxiliary constants for a given circuit. The voltage and current to be transmitted do not affect these constants. The resistance, reactance, conductance, and susceptance to neutral per mile are ascertained from the tables for one conductor of the circuit. These values are then multiplied by the length of the circuit in miles and set down as total per conductor.

The values of Y and Z must now be set down for the problem in the form of complex quantities. Thus $Z = R + jX = 105 + j240$ and $Y = G + jB = O + j0.001563$ since zero leakage conductance has been assumed for this case. Conductance G represents the true power loss in the form of leakage over insulators and of corona loss through the air between conductors. Corona loss corresponding to the assumed atmospheric conditions may be estimated by applying Peek's formula (See Section IV, Nov. 1919, on Corona). Insulator leakage may be approximated from the most suitable test data available. It is general practice in the solution of all but the very longest high-voltage circuits to ignore the effect of the losses due to leakage and corona effect. These losses will be ignored in this case, so that *G* becomes zero. After *Z* and *Y* have been written down in the form of complex quantities the product *YZ* should be found as previously described for the multiplication of complex quantities. The second, third and fourth power of *YZ* may then be found, if desired. Chart XI shows the fourth power, but on all but the longest circuits a total of four terms will be sufficient, and for most problems three terms will give sufficient accuracy. The range of accuracy has been previously indicated for a 300 mile circuit on the basis of any number of terms being used up to and including infinity. The values in Chart XI are carried out to six decimal places whereas four places will usually give sufficient accuracy for calculating the values of the constants *A* and *B*. The smallness of the value of constant *C* may make six places desirable when calculating its value.

CHART XI—EXAMPLE ILLUSTRATING RIGOROUS SOLUTION FOR THE AUXILIARY CONSTANTS BY CONVERGENT SERIES FOR PROBLEM X.

PHYSICAL CHARACTERISTICS OF CIRCUIT — FREQUENCY

LENGTH, 300 MILES. CYCLES, 60.
CONDUCTORS — #000 STRANDED COPPER.
SPACING OF CONDUCTORS 10 X 10 X 20 FEET.
EQUIVALENT DELTA SPACING = 12.6 FEET.

LINEAR LINE CONSTANTS

FROM TABLES — PER MILE

TABLE NO. 2, **r** = .350 OHM AT 25° C.
TABLE NO. 5, **x** = .830 OHM (BY INTERPOLATION).
TABLE NO. 10 **b** = 5.21 X 10^{-6} MHO (BY INTERPOLATION).
g = (IN THIS CASE TAKEN AS ZERO).

TOTAL PER CONDUCTOR

R = **rl** = .350 X 300 = 105 OHMS TOTAL RESISTANCE.
X = **xl** = .830 X 300 = 249 OHMS TOTAL REACTANCE.
B = **bl** = 5.21 X 300 X 10^{-6} = .001563 MHO TOTAL SUSCEPTANCE.
G = **gl** = 0 X 300 = 0 MHO TOTAL CONDUCTANCE.

MULTIPLICATION OF YZ

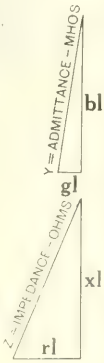
$Y = 0 + j\,.001563$
$Z = 105 + j\,249$
$0 \quad 0$
$-\,.389187 + j\,.164115$

$YZ = -\,.389187 + j\,.164115$
$YZ = -\,.389187 + j\,.164115$
$+\,.151466 - j\,.063871$
$-\,.026934 - j\,.063871$

$Y^2Z^2 = +\,.124532 - j\,.127742$
$YZ = -\,.389187 + j\,.164115$
$-\,.048466 + j\,.020437$
$+\,.020964 + j\,.049715$

$Y^3Z^3 = -\,.027502 + j\,.070152$
$YZ = -\,.389187 + j\,.164115$
$+\,.010703 - j\,.004513$
$-\,.011513 - j\,.027302$

$Y^4Z^4 = .000810 - j\,.031815$



NOTE

THE AUXILIARY CONSTANTS OF THE CIRCUIT (A) (B) & (C) MAY BE OBTAINED GRAPHICALLY FROM THE WILKINSON CHARTS

SOLUTION FOR (A)

$$(A) = \left[1 + \frac{YZ}{2} + \frac{Y^2Z^2}{24} + \frac{Y^3Z^3}{720} + \frac{Y^4Z^4}{40\,320} + \right].$$

$1.000\,000$

$\frac{YZ}{2} = -\,.194593 + j\,.082057$

$\frac{Y^2Z^2}{24} = +\,.005189 - j\,.005322$

$\frac{Y^3Z^3}{720} = -\,.000038 + j\,.000097$

$\frac{Y^4Z^4}{40\,320} = -\,.000000 - j\,.000001$

$(A) = +\,.810558 + j\,.076831$
$= (a_1 + j\,a_2)$
$= 0.8142 \angle 5^\circ\,24'\,53''$

SOLUTION FOR (B)

$$(B) = Z\left[1 + \frac{YZ}{6} + \frac{Y^2Z^2}{120} + \frac{Y^3Z^3}{5\,040} + \frac{Y^4Z^4}{362\,880} + \right].$$

$1.000\,000$

$\frac{YZ}{6} = -\,.064863 + j\,.027352$

$\frac{Y^2Z^2}{120} = +\,.001038 - j\,.001064$

$\frac{Y^3Z^3}{5{,}040} = -\,.000005 + j\,.000014$

$\frac{Y^4Z^4}{362\,880} = -\,.000000 - j\,.000000$

$(B) = Z(+\,.93617 + j\,.026302)$
$Z = 105 + j\,249$
$+\,98.2978 + j\,233.1063$
$-\,6.5492 + j\,2.7617$

$(B) = +\,91.7486 + j\,235.8680$
$= (b_1 + j\,b_2)$
$253.083 \angle 68^\circ\,44'\,41''$ OHMS

SOLUTION FOR (C)

$$(C) = Y\left[1 + \frac{YZ}{6} + \frac{Y^2Z^2}{120} + \frac{Y^3Z^3}{5.040} + \frac{Y^4Z^4}{362.880} + \right].$$

(C) [illegible]

(C) [illegible]

[illegible] MHO

After the values of *YZ*, Y^2Z^2, Y^3Z^3 etc., have been calculated they are divided by 2, 24, 720 etc., respectively, set down and added to 1. This gives the value of the auxiliary constant *A*, as + 0.810558 + *j* 0.076831 which is also referred to as $a_1 + ja_2$. The

CHART XII – AUXILIARY CONSTANTS OF VARIOUS CIRCUITS

PROBLEM NO	LENGTH OF CIRCUIT-(MILES)	CONDUCTORS	SPACING-DELTA	LINEAR CONSTANTS TOTAL PER CONDUCTOR ★				AUXILIARY CONSTANTS OF CIRCUIT THESE AUXILIARY CONSTANTS TAKE INTO ACCOUNT THE EFFECT OF DISTRIBUTED CAPACITANCE. THEY HAVE BEEN CALCULATED RIGOROUSLY BY CONVERGENT SERIES		
				rl FROM TABLE NO 2	xl FROM TABLE NOS 4 & 5	bl FROM TABLE NOS 9 & 10	gl	CONSTANT (A)	CONSTANT (B)	CONSTANT (C)
								a_1 a_2	b_1 b_2	c_1 c_2
25 CYCLES										
1	20	0000 COPPER	3	5.54	5.36	57.2	0	.999841 + j.000158	5.5394 + j5.3600	0 + j.000057
2	"	"	"	"	"	"	0	= [illegible] ∠0°0′32″	= 7.7081 ∠44°3′27″	= .000057 ∠90°0′0″
3	"	"	3	5.54	5.36	57.2	0	.999841 + j.000158	5.5394 + j5.3600	0 + j.000057
4	"	"	"	"	"	"	0	= [illegible] ∠0°0′32″	= 7.7081 ∠44°3′27″	= .000057 ∠90°0′0″
5	30	0000 COPPER	4	8.31	8.5	81.0	0	.999656 + j.000336	8.3082 + j8.4999	0 + j.000081
6	"	"	"	"	"	"	0	= .999656 ∠0°1′10″	= 11.886 ∠45°39′12″	= .000081 ∠90°0′0″
7	"	"	4	8.31	8.5	81.0	0	.999656 + j.000336	8.3082 + j8.4999	0 + j.000081
8	"	"	"	"	"	"	0	= .999656 ∠0°1′10″	= 11.886 ∠45°39′12″	= .000081 ∠90°0′0″
9	50	0000 COPPER	4	13.85	14.1	135	0	.999048 + j.000935	13.841 + j14.0996	0 + j.000135
10	"	"	"	"	"	"	0	= .999048 ∠0°3′12″	= 19.757 ∠45°31′44″	= .000135 ∠90°0′0″
11	"	"	6	13.85	15.1	125	0	.999056 + j.000866	13.8413 + j15.0991	0 + j.000125
12	"	"	"	"	"	"	0	= .999056 ∠0°2′58″	= 20.4833 ∠47°29′20″	= .000125 ∠90°0′0″
13	100	0000 COPPER	9	27.7	32.2	233	0	.996248 + j.003224	27.6307 + j32.1894	0 + j.000233
14	"	"	"	"	"	"	0	= .996253 ∠0°11′7″	= 42.4218 ∠49°21′28″	= .000233 ∠90°0′0″
15	"	"	11	27.7	33.2	226	0	.996249 + j.003126	27.6308 + j33.1874	0 + j.000226
16	"	"	"	"	"	"	0	= .996254 ∠0°10′47″	= 43.1841 ∠50°13′13″	= .000226 ∠90°0′0″
17	200	300M COPPER	11	39.2	64.8	464	0	.984991 + j.009049	38.808 + j64.594	−.000001 + j.000462
18	"	"	"	"	"	"	0	= .985033 ∠0°31′35″	= 75.356 ∠59°0′10″	= .000462 ∠90°7′27″
19	"	"	17	39.2	69.2	434	0	.985009 + j.008464	38.8084 + j68.965	−.000001 + j.000432
20	"	"	"	"	"	"	0	= .985050 ∠0°29′31″	= 79.134 ∠60°37′58″	= .000432 ∠90°7′54″
21	300	636M ALUM.	11	44.1	91.2	747	0	.966085 + j.016285	43.1033 + j90.408	−.000004 + j.000739
22	"	"	"	"	"	"	0	= .966222 ∠0°57′1″	= 100.157 ∠64°30′36″	= .000739 ∠90°17′10″
23	"	"	21	44.1	101	672	0	.966219 + j.014650	43.1070 + j100.077	−.000003 + j.000664
24	"	"	"	"	"	"	0	= .966330 ∠0°52′6″	= 108.966 ∠66°41′48″	= .000664 ∠90°15′24″
25	400	636M ALUM.	17	58.8	130	928	0	.940161 + j.026738	56.4555 + j127.927	−.000008 + j.000909
26	"	"	"	"	"	"	0	= .940541 ∠1°37′45″	= 139.83 ∠66°11′16″	= .000909 ∠90°30′14″
27	"	"	21	58.8	134	896	0	.940452 + j.025819	56.4664 + j131.842	−.000008 + j.000878
28	"	"	"	"	"	"	0	= .940801 ∠1°34′20″	= 143.425 ∠66°48′54″	= .000878 ∠90°31′18″
29	500	636M ALUM.	17	73.5	163	1160	0	.906642 + j.041299	68.928 + j158.928	−.000016 + j.001124
30	"	"	"	"	"	"	0	= .907583 ∠2°36′14″	= 173.23 ∠66°33′13″	= .001124 ∠90°48′56″
31	"	"	21	73.5	168	1120	0	.907109 + j.039880	68.9501 + j163.76	−.000[illegible]5 + j.001085
32	"	"	"	"	"	"	0	= .907985 ∠2°31′2″	= 177.684 ∠67°10′0″	= .001085 ∠90°4[illegible]′33″
60 CYCLES										
33	20	0000 COPPER	3	5.54	12.88	137	0	.999118 + j.000379	5.53675 + j12.8769	0 + j.000137
34	"	"	"	"	"	"	0	= .999118 ∠0°1′18″	= 14.0167 ∠66°44′0″	= .000137 ∠90°0′0″
35	"	"	3	5.54	12.88	137	0	.999118 + j.000379	5.53675 + j12.8769	0 + j.000137
36	"	"	"	"	"	"	0	= .999118 ∠0°1′8″	= 14.0167 ∠66°44′0″	= .000137 ∠90°0′0″
37	30	0000 COPPER	4	8.31	20.4	195	0	.998011 + j.00081	8.299 + j20.3887	0 + j.000195
38	"	"	"	"	"	"	0	= .998011 ∠0°2′47″	= 22.014 ∠67°51′6″	= .000195 ∠90°0′0″
39	"	"	4	8.31	20.4	195	0	.998011 + j.00081	8.299 + j20.3887	0 + j.000195
40	"	"	"	"	"	"	0	= .998011 ∠0°2′47″	= 22.014 ∠67°51′6″	= .000195 ∠90°0′0″
41	50	0000 COPPER	4	13.85	34.0	324	0	.994496 + j.002239	[illegible]3.7992 + j33.9479	0 + j.000323
42	"	"	"	"	"	"	0	= .994498 ∠0°7′33″	= 36.645 ∠67°52′45″	= .000323 ∠90°0′0″
43	"	"	6	13.85	36.4	30[illegible]	0	.994526 + j.002081	13.7994 + j36.3432	0 + j.000300
44	"	"	"	"	"	"	0	= .994528 ∠0°7′4″	= 38.874 ∠69°2′30″	= .000300 ∠90°0′0″
45	[illegible]00	0000 COPPER	9	27.7	[illegible]	[illegible]	0	.97832 + j.00[illegible]8	[illegible].2996 + j76.9116	−.00000[illegible] + j.000558
46	"	"	"	"	"	"	0	= .9[illegible]835 ∠0°27′10″	= 8[illegible].6129 ∠70°27′36″	= .000558 ∠90°[illegible]
47	"	"	11	27.7	79.7	542	0	.9[illegible]847 + j.00[illegible]452	27.302 + j79.[illegible]63	−.00000[illegible] + j.000538
48	"	"	"	"	"	"	[illegible]	= .9[illegible]8498 ∠0°26′[illegible]4″	= 83.77 ∠70°58′30″	= .000538 ∠90°[illegible]
[illegible]	200	300M COPPER	[illegible]	39.[illegible]	[illegible]	[illegible]	[illegible]	.9[illegible]4[illegible]28 + j.02[illegible]243	36.954 + j[illegible]5[illegible]	−.00000[illegible]8 + j.00[illegible]
[illegible]	"	"	"	"	"	"	[illegible]	= .9[illegible]43[illegible] ∠[illegible]°9′31″	= [illegible]56.224 ∠[illegible]6°[illegible]9′2″	= .001084 ∠90°2[illegible]
[illegible]	"	"	[illegible]	39.2	[illegible]	[illegible]	0	.914524 + j.019876	[illegible] + j6[illegible].50[illegible]	−.0000[illegible] + j.00[illegible]
[illegible]	"	"	"	"	"	"	0	= [illegible] ∠[illegible]°4′40″	= [illegible]	= .001014 ∠90°23′43″
[illegible]	300	[illegible]	[illegible]	44.[illegible]	[illegible]	[illegible]	0	.80[illegible] + j.0[illegible]	[illegible] + j20[illegible].35[illegible]	−.0000[illegible]3 + j.00[illegible]
[illegible]	"	"	"	"	"	"	0	= [illegible]	= 209.9[illegible] ∠[illegible]°26′29″	= [illegible]
[illegible]	"	"	21	44.[illegible]	[illegible]	[illegible]	0	.8[illegible] + j.03330[illegible]	[illegible] + j22[illegible].918	−.000018 + j.001510
[illegible]	"	"	"	"	"	"	0	= [illegible]	= [illegible]23[illegible] ∠80°24′[illegible]	= [illegible]
[illegible]	400	[illegible]	17	58.8	314	2212	[illegible]	.671701 + j.057759	[illegible] + j28[illegible]	[illegible]
[illegible]	"	"	[illegible]	"	[illegible]	"	0	= [illegible]	= [illegible]	= [illegible]
[illegible]	"	[illegible]	21	[illegible]	[illegible]	[illegible]	0	[illegible] + j.0[illegible]8	[illegible] + j28[illegible]	[illegible]
[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	= [illegible]	= [illegible]	= [illegible]
[illegible]	[illegible]	[illegible]	[illegible]	73.5	[illegible]	2785	[illegible]	[illegible]	[illegible]	[illegible] + j.0023[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	"	0	= [illegible]	= [illegible]	= [illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2690	0	[illegible]	[illegible]	−.000079 + j.002230
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	"	[illegible]	[illegible]	= [illegible]	= [illegible]	= [illegible]

*rl is the resistance in ohms at 25° C (77° F), xl the reactance in ohms, bl the susceptance in microhms to neutral (multiply by 10^{-6} to convert to ohms). The x and b values for the 636 000 circ. mil aluminum cable were taken as those of 700 000 circ. mil copper on the assumption that these two conductors would have approximately the same diameter. gl, the loss resulting from leakage over insulators and from corona has, for simplicity, been assumed as zero.

absolute value of the constant $A = 0.8142$ is simply the square root of the sum of the square of a_1 and a_2. The polar value of A is thus 0.8142 $/5° 24' 53''$.

The solution for the constant B is of the same general form as the solution for the constant A, except that the values of YZ, $Y^2 Z^2$, and $Y^3 Z^3$ etc., are divided by *6*, *120* and *5040* respectively. After these results are added to *1* they are multiplied by Z, the product being the value of the auxiliary constant B or $b_1 + jb_2$. The absolute value of B is obtained in the same manner as the absolute value of A.

The solution for C is the same as for B except that in place of the constant B series being multiplied by Z it is multiplied by Y and the values of C or $c_1 + jc_2$ obtained.

AUXILIARY CONSTANTS OF VARIOUS CIRCUITS

In Chart XII are tabulated exact values for the auxiliary constants for the 64 problems to which frequent reference will be made. These auxiliary constants have been calculated by convergent series, the results having been checked through the medium of three separate calculations made at different times. They are therefore believed exact to at least five significant digits. The results have been expressed in both rectangular and polar co-ordinates.

CALCULATIONS OF PERFORMANCE

In Chart XIII is given the complete calculation of the electrical performance for problem X, starting with the values for the auxiliary constants and the receiving end load conditions known. The calculations are carried out by the employment of complex numbers, the complete performance being calculated for both load and zero load conditions. In order to give a more clear understanding of these mathematical operations the reader is referred to the vector diagrams of Fig. 37.

In Chart XIII are given the formulas for determining the E_s and I_s values under load conditions. On Fig. 37 these two same formulas are given, but in the form of vector diagrams, upon which vectors the numerical values corresponding to problem X are stated. With the numerical values of the vectors and angles stated, it should be a comparatively simple manner to follow graphically (Fig. 37) the mathematical calculations shown in Chart XIII.

The formulas for E_s and I_s which are stated in Chart XIII and in Fig. 37 contain a complex number ($\cos \theta_r \pm j \sin \theta_r$) not previously stated in connection with the fundamental hyperbolic formulas for long circuits. The formulas previously given were based upon unity power-factor. The introduction of this new complex number is made necessary in order that the effect of the power-factor of the load current may be included in the calculations. The function of this new complex number is to rotate the current vector through an angle corresponding to the power-factor of the load current. It will be referred to as the rotating triangle. If the load power-factor is 100 percent, this rotating triangle will equal $1 \pm j\,0$, hence it has no effect or power to rotate. If the power-factor of the load is 80 percent the rotating triangle would have a numerical value of $0.8 \pm j\,0.6$.

The various phase angles given in Chart XIII show whether the power-factor at the supply end is leading or lagging. These various phase angles are given to make the discussion complete. Actually, in order to determine whether the power-factor at the supply end is leading or lagging, it is only necessary to note if the supply end current vector leads or lags behind the supply end voltage vector. At the lower end of Fig. 37 combined current and voltage vectors are shown for this problem, corresponding to both load and zero load conditions.

In Chart XIV is given a complete calculation of the electrical performance of problem X, starting with the values for the auxiliary constants and the sending end load condition known. In other words the supply end conditions which were derived by calculation in Chart XIII have in this case been assumed as fixed, and the receiver end conditions calculated. The reason that there is a slight difference between the receiving end conditions as calculatd on Chart XIV and the known receiving end conditions is that the value for the sine in the rotating triangle (0.436) in Chart XIII was carried out to only three places, whereas in Chart XIV it was carried out to four places. If the values for the rotating triangles had been carried out to five or six places in the calculations in both charts, the receiving end conditions would have checked exactly.

TERMINAL VOLTAGES AT ZERO LOAD

For a given circuit and frequency, the relation of the voltage at the two ends of the circuit is fixed. The ratio of sending end to the receiving end voltage is expressed by the constant A. The ratio of receiving to sending end voltage is expressed by $\frac{1}{A}$. For example, problem X, the sending end voltage under load is 70 652 volts. If the load is thrown off, and this sending end voltage is maintained constant at 70 652 volts, the receiving end voltage will rise to a value of $\frac{70\,652}{0.8142}$ 86 775 volts to neutral. The rise in percent of sending end voltage is therefore $\frac{100\,(86\,775 - 70\,652)}{70\,652}$ 22.82 percent.

PERFORMANCE OF VARIOUS CIRCUITS

In Chart XV is tabulated the complete performance of the 64 problems for which the auxiliary constants are tabulated in Chart XII. The auxiliary constants in Chart XII were applied to the fixed load conditions as stated in Chart XV for the receiving end, and both load and zero load conditions at the sending end were calculated and tabulated.

The object of calculating and tabulating the values for the 64 problems was two fold. First to obtain data on 25 and 60 cycle problems covering a wide range

CHART XIII—RIGOROUS CALBULATION OF PERFORMANCE WHEN RECEIVING END CONDITIONS ARE FIXED

$KV\text{-}A_R$ 8 000. KW_R 16 200. E_R 104 000 VOLTS 3 PHASE. PF_R = 90.00% LAGGING.

PER PHASE TO NEUTRAL

$KV\text{-}A_{RN} = \frac{8\,000}{3} = 6\,000$. $KW_{RN} = \frac{16\,200}{3} = 5\,400$. $E_{RN} = \frac{104\,000}{1.732} = 60\,046$. $I_R = \frac{6\,000 \times 1000}{60\,046}$ = [illegible] AMPERES.

AUXILIARY CONSTANTS OF CIRCUIT

$(A) = +.810558 + j.076831$
$= (a_1 + j a_2)$
$= .8142 \angle 5^\circ 24' 53''$

$(B) = +91.7486 + j\,235.868$
$= (b_1 + j\,b_2)$
$= 253.083 \angle 68^\circ 44'$ [illegible] OHMS

$(C) =$ [illegible]
$(c_1 + j\,c_2)$
$= .00464 \angle 91^\circ 35'$ [illegible] MHO

LOAD CONDITIONS

SOLUTION FOR E_S

$$E_S = E_R(a_1 + j a_2) + I_R(\cos\theta_R \pm j\sin\theta_R)(b_1 + j b_2) \bigstar$$

★ ± THIS SIGN IS MINUS WHEN THE P. F. IS LAGGING AND PLUS WHEN THE P. F. IS LEADING

$(a_1 + j a_2) \quad +.810558 + j.076831$
$\times E_{RN} \quad 60046$
$E_{RN}(a_1 + j a_2) \quad +48671 + j\,4613$

$(\cos\theta_R - j\sin\theta_R) \quad +.9 - j.436$
$\times I_R \quad 99.92$
$I_R(\cos\theta_R - j\sin\theta_R) \quad +89.93 - j\,43.56$
$\times (b_1 + j\,b_2) \quad +91.75 + j\,235.87$
$+8251 + j\,21212$
$+10274 - j\,3997$

$I_R(\cos\theta_R - j\sin\theta_R)(b_1 + j\,b_2) \quad +18525 + j\,17215$
$+E_{RN}(a_1 + j a_2) \quad +48671 + j\,4613$
$E_{SN} \quad +67196 + j\,21828$
$= \sqrt{67\,196^2 + 21828^2}$
E_{SN} = 70 652 VOLTS TO NEUTRAL

SOLUTION FOR I_S

$$I_S = I_R(\cos\theta_R \pm j\sin\theta_R)(a_1 + j a_2) + E_R(c_1 + j c_2) \bigstar$$

$I_R(\cos\theta_R - j\sin\theta_R) \quad +89.93 - j\,43.56$
$\times (a_1 + j a_2) \quad +.810558 + j.076831$
$+72.893 + j\,6.909$
$+3.347$ [illegible]
$I_R(\cos\theta_R - j\sin\theta_R)(a_1 + j a_2) = +76.240 - j$ [illegible]

$(c_1 + j\,c_2) =$ [illegible]
$\times E_{RN} \quad 60046$
$E_{RN}(c_1 + j\,c_2)$ [illegible]
$+I_R(\cos\theta_R - j\sin\theta_R)(a_1 + j a_2) \quad +76.240$ [illegible]
$I_S = +73.778 + j\,59.451$
$= \sqrt{73.778^2 + 59.451^2}$
I_S = 94.75 AMPERES.

KW_{SN} = (67.196 X 73.778) + (21.828 X 59.451) = 6.255 KW PER PHASE.

$KV\text{-}A_{SN}$ = (70.652 X 94.75) = 6 694 KV-A PER PHASE.

$LOSS_N$ = 6255 − 5400 = 855 KW PER PHASE.

EFFICIENCY $= \frac{5\,400 \times 100}{6\,255}$ = 86.33%.

$PF_S = \frac{6\,255 \times 100}{6\,694}$ = 93.42% LEADING.

PHASE ANGLES—AT FULL LOAD THE VOLTAGE AT THE SENDING END LEADS THE VOLTAGE AT THE RECEIVER END BY THE ANGLE $\tan^{-1}\frac{21\,828}{67196} = \tan^{-1}.325 = 18^\circ 00'$. AND THE CURRENT AT THE SENDING-END LEADS THE VOLTAGE AT THE RECEIVING-END BY THE ANGLE $\tan^{-1}\frac{59.451}{73.778} = \tan^{-1}.806 = 38^\circ 52'$. HENCE THE CURRENT AT THE SENDING-END LEADS THE VOLTAGE AT THE SENDING-END BY THE ANGLE 38° 52′ − ANGLE 18° 00′ = 20° 52′. THE POWER-FACTOR AT THE SENDING-END IS THEREFORE COS 20° 52′ = 93.42% LEADING AT LOAD SPECIFIED.

ZERO LOAD CONDITIONS

E_{SN} = [illegible]
E_{SN} = [illegible]

I_{SO} = $-2.462 - j\,87.85$
$= \sqrt{2.462^2 + 87.85^2}$
I_{SO} = 87.89 AMPERES.

KW_{SN} = [illegible] KW PER PHASE.
$KV\text{-}A_{SN}$ = [illegible] KV-A PER PHASE.
PF = [illegible] LEADING.

REGULATION

A RISE IN VOLTAGE AT THE SENDING END OCCURS OF 70 652 − 48 889 = 21 763 VOLTS TO NEUTRAL WHEN THE LOAD IS INCREASED FROM ZERO TO 99.92 AMPERES AT 90% POWER FACTOR LAGGING AT THE RECEIVER END WITH CONSTANT VOLTAGE AT THE RECEIVING END.

PHASE ANGLES

AT ZERO LOAD THE VOLTAGE AT THE SENDING-END LEADS THE VOLTAGE AT THE RECEIVER END BY THE ANGLE $\tan^{-1}\frac{4\,613}{48\,671} =$ TAN⁻¹ .0947 [illegible] AND THE [illegible] AT THE SUPPLY END LEA[illegible]

TAN (−35.7) = 91° 36′ — HENCE THE CURRENT AT THE SUPPLY END LEADS THE VOLTAGE AT THE SUPPLY END BY THE ANGLE (91° 36′) − (5° 25′) = 86° 11′. THE POWER FACTOR AT THE SENDING-END IS THEREFORE COS 86° 11′ = 6.64% LEADING AT ZERO LOAD.

which would provide a basis for constructing curves, illustrating the effect that distance in transmission has upon the performance of circuits and upon the auxiliary constants of the circuit. Second, to give the student a wide range of problems from which he could choose, and from which he could start with the tabulated values as fixed at either end and calculate the conditions at the other end. It is believed that such problems will furnish very profitable practice for the student and will also serve as a general guide when making calculations on problems of similar length and fundamental or lineal constants. It is not intended that the figures given for longer circuits, included in these tabulations, shall coincide with ordinary conditions encountered in practice.

CHART XIV—RIGOROUS CALCULATION OF PERFORMANCE WHEN SENDING END CONDITIONS ARE FIXED

$KV\text{-}A_S = 20\,082$. $KW_S = 18\,765$. $E_S = 122\,369$ VOLTS 3 PHASE. $PF_S = 93.42\%$ LEADING.

PER PHASE TO NEUTRAL

$KV\text{-}A_{SN} = \frac{20\,082}{3} = 6\,694$. $KW_{SN} = \frac{18\,765}{3} = 6\,255$. $E_{SN} = \frac{122\,369}{1.732} = 70\,652$. $I_S = \frac{6\,694 \times 1000}{70\,652} = 94.75$ AMPERES.

AUXILIARY CONSTANTS OF CIRCUIT

$(A) = +.81056 + j.076831 = (a_1 + j a_2) = .8142\ \underline{/5\ 24\ 50'}$

$(B) = +91.7486 + j\,235.868 = (b_1 + j b_2) = 253.083\ \underline{/68\ 44\ 41'}$ OHMS

$(C) = -.000041 + j.001463 = (c_1 + j c_2) = .001464$ [illegible] MHOS

LOAD CONDITIONS

SOLUTION FOR E_R

$$E_R = E_S(a_1 + j a_2) - I_S(\cos\theta_S \pm j \sin\theta_S)(b_1 + j b_2)\bigstar$$

★ ± THIS SIGN IS MINUS WHEN THE P. F. IS LAGGING AND PLUS WHEN THE P. F. IS LEADING

$(a_1 + j a_2) = +.81056 + j.076831$

$\times E_{SN} = +70652$

$E_{SN}(a_1 + j a_2) = +57268 + j\,5428$

$(\cos\theta_S + j \sin\theta_S) = +.9342 + j.3567$

$\times I_S = +94.7$

$I_S(\cos\theta_S + j \sin\theta_S) = +88.52 + j\,33.8$

$\times (b_1 + j b_2) = +91.75 + j\,235.9$

$+$ [illegible]22 + [illegible]

$-\ 7973 + j$ [illegible]

$I_S(\cos\theta_S + j \sin\theta_S)(b_1 + j b_2) = +149 + j\,23983$

$E_{SN}(a_1 + j a_2) = +57268 + j\,5428$

$-I_S(\cos\theta_S + j \sin\theta_S)(b_1 + j b_2) = -149 - j\,23983$ ← CHANGE SIGNS AND ADD

$E_{RN} = +57119 - j\,18555$

$= \sqrt{(57119)^2 + (18555)^2}$

$E_{RN} = 60\,057$ VOLTS TO NEUTRAL.

SOLUTION FOR I_R

$$I_R = I_S(\cos\theta_S \pm j \sin\theta_S)(a_1 + j a_2) - E_S(c_1 + j c_2)\bigstar$$

$I_S(\cos\theta_S + j \sin\theta_S) = +88.52 + j$ [illegible]

$\times (a_1 + j a_2) = +.81056 + j.076831$

$+$ [illegible] $+ j\,6.801$

[illegible] $+ j$ [illegible]

$I_S(\cos\theta_S + j \sin\theta_S)(a_1 + j a_2) = +$ [illegible] $+ j$ [illegible]

$(c_1 + j c_2) = -.000041 + j.001463$

$\times E_{SN} = 70652$

$E_{SN}(c_1 + j c_2) = -2.897 + j$ [illegible]

$I_S(\cos\theta_S + j \sin\theta_S)(a_1 + j a_2) = +69.154 + j$ [illegible]

CHANGE SIGNS AND ADD → $-E_{SN}(c_1 + j c_2) = +2.897 - j$ [illegible]

$I_R = 72.051 - j\,69.16$

$= \sqrt{(72.051)^2 + (69.16)^2}$

$I_R = 99.87$ AMPERES.

$KW_{RN} = (57.119 \times 72.051) + (18.555 \times 69.16) = 5\,399$ KW PER PHASE.

$KV\text{-}A_{RN} = (60.057 \times 99.87) = 5\,998$ KV-A PER PHASE.

$LOSS_N = 6\,255 - 5\,399 = 856$ KW PER PHASE.

$PF_R = \frac{5\,399 \times 100}{5\,998} = 90.01\%$ LAGGING.

$EFFICIENCY = \frac{5\,399 \times 100}{6\,255} = 86.32\%$.

PHASE ANGLES AT FULL LOAD THE VOLTAGE AT THE RECEIVER END LAGS BEHIND THE VOLTAGE AT THE SENDING-END BY THE ANGLE $\tan^{-1}\frac{18\,555}{57\,119} = \tan^{-1}.325 = 18°\,0'$; AND THE CURRENT AT THE RECEIVER END LAGS BEHIND THE VOLTAGE AT THE SENDING-END BY THE ANGLE $\tan^{-1}\frac{69.16}{72.051} = \tan^{-1}.959 = 43°\,50'$. HENCE THE CURRENT AT THE RECEIVER END LAGS BEHIND THE VOLTAGE AT THE RECEIVER END BY THE ANGLE 43° 50' − ANGLE 18° 0' = 25° 50'. THE POWER-FACTOR AT THE RECEIVER END IS THEREFORE COS 25° 50' = 90% LAGGING.

ZERO LOAD CONDITIONS

$$\underline{E_{RNO}} = \frac{E_{SNO}(a_1 - j a_2)}{(a_1^2 + a_2^2)} = \frac{48\,898\,(.81056 - j.076831)}{(.81056)^2 + (.076831)^2} = \frac{39635 - j\,3757}{6629} = 59\,790 - j\,5667 = 60\,058 \text{ VOLTS.}$$

$$\underline{I_{SO}} = E_{SNO}\frac{(c_1 a_1 + c_2 a_2) + j(c_2 a_1 - c_1 a_2)}{(a_1^2 + a_2^2)} = 48\,898\ \frac{(-.00004 \times .81056 + .001463 \times .07683) + j(\text{[illegible]})}{6629}$$

$$\underline{I_{SO}} = 48\,898\ \frac{(+.0000792 + j.001189)}{.6629} = 48\,898\,(.000119 + j.001794) = 48\,898 \times .001798 = 87.92 \text{ AMPERES.}$$

REGULATION

A RISE IN VOLTAGE AT THE SENDING-END OCCURS OF 70 652 − 48 898 = 21 754 VOLTS TO NEUTRAL WHEN THE LOAD IS INCREASED FROM ZERO TO 99.87 AMPERES AT 90.01% POWER FACTOR LAGGING AT THE RECEIVER END WITH CONSTANT VOLTAGE AT THE RECEIVING END.

PHASE ANGLES

AT ZERO LOAD THE VOLTAGE AT THE RECEIVER END LAGS BEHIND THE VOLTAGE AT THE SENDING-END BY THE ANGLE $\tan^{-1}\frac{5\,667}{59\,790} = \tan^{-1}.0948 = 5°\,25'$; AND THE CURRENT AT THE SENDING-END LEADS THE VOLTAGE AT THE SENDING-END BY THE ANGLE $\tan^{-1}\frac{.001794}{.000119} = \tan^{-1}15.08 = 86°\,11'$. THE POWER-FACTOR AT THE SENDING-END IS THEREFORE COS 86° 11' = 6.64% LEADING AT ZERO LOAD.

CHART XV—CALCULATED PERFORMANCE OF VARIOUS CIRCUITS

PROBLEM	RECEIVING-END CONDITIONS FIXED							SENDING-END CONDITIONS—CALCULATED ★											
	LOAD CONDITIONS							LOAD CONDITIONS							ZERO LOAD				
			TO NEUTRAL					TO NEUTRAL							TO NEUTRAL				
	KV-A R	E R 3 PHASE	KV-A RN	KW RN	E RN	I R	PF R %	KV-A SN	KW SN	E SN	I S	★★ PF S %	LINE DROP IN % OF E RN	LINE LOSS IN % OF KW R	KV-A SNO	KW SNO	E SNO	I SO	PF SO %
25 CYCLES																			
1	[illegible]	[illegible]	433.3	346.6	5 774	75	80 LAG.	474.63	377.52	6 347	74.78	79.53	-9.92	8.92	1.963		5 773	.34	
2	"	"	"	433.3	"	"	100	[illegible]	464.21	6 202	74.99	99.8	-7.41	7.13	"		"	"	
3	[illegible]	[illegible]	[illegible]	1333.3	11 550	144.4	80 LAG.	[illegible]	1449.5	[illegible]	143.99	[illegible]	-9.55	8.71	7.622		11 548	.66	
4		"	"	[illegible]	"	"	100	1786.3	[illegible]	12 372	144.38	99.80	-7.12	7.00	"		"	"	
5	[illegible]	20 000	[illegible]	933	11 550	101	80 LAG	[illegible]	[illegible]	[illegible]	100.42	79.58	-10.24	9.05	10.85		11546	.94	
6	"	"	"	[illegible]	"	"	100	[illegible]	[illegible]	12 415	100.97	99.82	-7.49	7.22	"		"	"	
7	8000	[illegible]	2667	2133	[illegible]	154	80 LAG.	2 423.2	[illegible]	[illegible]	153.1	79.56	-10.42	9.23	24.29		17 313	1.403	
8	"	"	"	2 667	"	"	100	2 369.8	[illegible]	[illegible]	53.96	99.68	-7.62	7.26	"		"	"	
9	[illegible]	30 000	[illegible]	1333	[illegible]	96.2	80 LAG.	[illegible]	[illegible]	[illegible]	94.73	80.29	-10.76	9.47	40.32		17 304	2.33	
10		"	"	1667	"	"	100	[illegible]	1794.2	[illegible]	96.14	99.88	-7.89	7.63	"		"	"	
11	[illegible]	[illegible]	[illegible]	5 333	[illegible]	[illegible]	80 LAG.	[illegible]	[illegible]	[illegible]	[illegible]	79.97	-11.11	9.53	149.8	.13	34 607	4.33	.09
12	"	"	"	[illegible]	"	"	100	[illegible]	7181.2	[illegible]	92.37	99.85	-7.93	7.71	"	"	"	"	"
13	[illegible]	83 000	[illegible]	[illegible]	[illegible]	144.4	80 LAG.	[illegible]	[illegible]	[illegible]	[illegible]	82.70	-11.43	9.42	599.3	1.94	50 620	11.84	.32
14	"	"	"	[illegible]	"	"	100	[illegible]	7 915.2	[illegible]	44.39	[illegible]	-7.89	7.94	"	"	"	"	"
15	40 000	120 000	13 333	[illegible]	69 290	192.5	80 LAG.	[illegible]	[illegible]	[illegible]	182.85	82.58	[illegible]	9.19	1081	3.39	69 030	15.66	.31
16	"	"	"	3 333	"	"	100	14 366	[illegible]	[illegible]	92.47	100.00	-7.73	7.75	"	"	"	"	"
17	[illegible]	120 000	8 333	6 667	69 290	120.3	80 LAG.	[illegible]	7156.1	[illegible]	102.75	90.74	-10.77	7.34	2185	5.29	68 253	[illegible]	.70
18	"	"	"	8 333	"	"	100	[illegible]	[illegible]	[illegible]	122.96	[illegible]	-5.93	6.96	"	"	"	"	"
19	[illegible]	140 000	13 333	10 667	80 830	165	80 LAG.	[illegible]	[illegible]	[illegible]	144.52	[illegible]	-13.52	8.84	2780	17.44	[illegible]	34.92	[illegible]
20	"	"	"	13 333	"	"	100	[illegible]	[illegible]	[illegible]	66.46	99.68*	-7.46	8.09	"	"	"	"	"
21	[illegible]	[illegible]	6 667	5 333	69 290	96.2	80 LAG	5 683.2	[illegible]	[illegible]	75.08	99.29	-9.22	5.81	3428	39.22	66 950	[illegible]	[illegible]
22		"	"	6 667	"	"	100	[illegible]	[illegible]	[illegible]	106.64	92.85*	-3.57	6.57	"	"	"	"	"
23	[illegible]	200 000	20 000	16 000	115 500	173.2	80 LAG.	[illegible]	[illegible]	128 450	136.83	96.99	-11.21	6.55	8559	91.03	[illegible]	[illegible]	[illegible]
24		"	"	20 000	"	"	100	[illegible]	[illegible]	120 574	84.64	95.98*	-4.34	6.90	"	"	"	"	"
25	[illegible]	140 000	[illegible]	5 333	80 830	82.5	80 LAG	[illegible]	5621.1	[illegible]	68.97	94.33*	-6.89	5.40	5585	109.6	[illegible]	[illegible]	[illegible]
26		"	"	[illegible]		"	100	8 808.9	[illegible]	[illegible]	[illegible]	81.34*	-1.01	7.47	"	"	"	"	"
27	[illegible]	[illegible]	[illegible]	3 333	[illegible]	[illegible]	80 LAG.	[illegible]	14 222	[illegible]	112.32	99.49*	-10.19	6.67	11 018	202.04	[illegible]	[illegible]	1.84
28	"	"	"	[illegible]	"	"	100	20 322	18 066	[illegible]	[illegible]	88.90*	-2.89	8.40		"	"	"	"
29	[illegible]	[illegible]	5 000	4 000	[illegible]	61.86	80 LAG.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-2.74	5.92	6 665	208.54	[illegible]	[illegible]	3.13
30		"	"	5 000	"	"	100	[illegible]	5 479	[illegible]	108.30	64.32*	+2.69	9.58	"	"			"
31	[illegible]	200 000	13 333	[illegible]	[illegible]	[illegible]	80 LAG	[illegible]	11 383	[illegible]	107.59	85.74*	-6.85	6.71	13 140	395.8	[illegible]	[illegible]	3.01
32	"	"		13 333	"	"	100	[illegible]	[illegible]	115 162	165.82	76.83*	[illegible]	10.05	"	"	"	"	"
60 CYCLES																			
33	[illegible]	[illegible]	433.3	[illegible]	5 774	75	80 LAG.	499.03	[illegible]	[illegible]	[illegible]	75.63	-16.07	8.90	4.558		[illegible]	.79	
34		"		433.3	"	"	100	[illegible]	[illegible]	[illegible]	[illegible]	98.96	-8.40	7.13	"		"	"	
35	5 000	[illegible]	[illegible]	[illegible]	[illegible]	144.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	75.82	[illegible]	8.70	[illegible]		[illegible]	[illegible]	
36	"	"		[illegible]	"	"	100	[illegible]	1783.3	[illegible]	44.28	99.04	8.05	6.98	"		"	"	
37	[illegible]	[illegible]	[illegible]	[illegible]	11 550	101	80 LAG.	[illegible]	[illegible]	[illegible]	[illegible]	75.82	[illegible]	8.98	25.93		[illegible]	2.25	
38	"	"	"	[illegible]	"	"	100	[illegible]	[illegible]	[illegible]	[illegible]	98.99	[illegible]	7.22	"			"	
39	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	154	80 LAG.	[illegible]	[illegible]	20 268	[illegible]	75.74	[illegible]	9.13	58.43		[illegible]	3.38	
40	"	"	"	[illegible]	"	"	100	[illegible]	[illegible]	[illegible]	[illegible]	98.94	8.72	7.39	"		"	"	
41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	80 LAG.	[illegible]	14562	[illegible]	92.43	[illegible]	-17.38	9.24	96.29	.22	17225	5.59	.22
42	"		"	[illegible]	"	"	100	[illegible]	[illegible]	[illegible]	95.84	99.33	-8.80	[illegible]	"	"	"	"	"
43	[illegible]	[illegible]	[illegible]	5 333	34 640	[illegible]	80 LAG.	[illegible]	[illegible]	40 976	[illegible]	76.73	-18.29	9.32	[illegible]	.75	34 450	10.39	.21
44	"		"	[illegible]	"	"	100	[illegible]	[illegible]	[illegible]	191.75	99.13	-9.05	7.70	"	"	"	"	"
45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	144.4	80 LAG.	[illegible]	[illegible]	59 925	[illegible]	[illegible]	-17.94	8.74	1 409	8.62	49 710	28.35	.61
46	"			[illegible]	"	"	100	[illegible]	[illegible]	[illegible]	144.26	100.00	-7.99	7.94	"	"	"	"	"
47	[illegible]	[illegible]	[illegible]	10 667	[illegible]	[illegible]	80 LAG.	[illegible]	11 579	81 710	[illegible]	[illegible]	[illegible]	8.55	2 528	[illegible]	67 800	37.28	.57
48	"		"	[illegible]	"	"	100	[illegible]	[illegible]	[illegible]	192.22	[illegible]	-7.86	7.74	"	"	"	"	"
49	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20.3	80 LAG.	[illegible]	7 075.1	[illegible]	89.65	99.89	-14.01	[illegible]	[illegible]	75.47	63 357	75.11	1.59
50		"	"	8 333	"	"	100	[illegible]	[illegible]	70 599	[illegible]	94.47*	-1.89	7.40	"	"	"	"	"
51	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	165	80 LAG.	[illegible]	[illegible]	[illegible]	122.27	96.90	-19.67	7.44	6 060	89.78	73 938	81.96	1.48
52		"	"	13 333	"	"	100	14 666	[illegible]	[illegible]	172.82	98.44	-4.99	8.29	"	"	"	"	"
53	20 000	[illegible]	[illegible]	5 333	[illegible]	96.2	80 LAG.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-4.99	5.50	[illegible]	208.8	56 101	116.27	3.20
54	"		"	[illegible]	"	"	100	[illegible]	[illegible]	63 810	[illegible]	[illegible]	+7.91	8.59	"	"	"	"	"
55	[illegible]	200 000	[illegible]	[illegible]	[illegible]	[illegible]	80 LAG.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-9.56	5.68	[illegible]	[illegible]	93 636	174.4	2.92
56		"		[illegible]	"	"	100	[illegible]	21 658	[illegible]	227.09	87.34*	[illegible]	8.29	"	"	"	"	"
57	20 000	[illegible]	[illegible]	5 333	[illegible]	[illegible]	80 LAG.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	+8.22	8.69	[illegible]	[illegible]	54 494	158.3	6.33
58				[illegible]	"	"	100	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	+20.35	[illegible]	"	"	"	"	"
59	[illegible]	[illegible]	[illegible]	13 333	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	+1.64	[illegible]	17 217	[illegible]	[illegible]	220.9	6.14
60				[illegible]	"	"	100	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	+16.03	2.54		"	"	"	"
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	173.30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	41 213	[illegible]	[illegible]
[illegible]					"	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	24.60	"	"	"	"	"
[illegible]	[illegible]			[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	14.82	[illegible]	[illegible]	[illegible]	257.7	12.52
[illegible]													[illegible]	20.15	"		"	"	"

★[illegible] from values [illegible] the auxiliary constants as given in Chart XII

Vacuum and Heat Treatment of Insulating Materials

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MUCH WORK has been done by various experimenters on the resistance of insulating materials under different conditions of temperature, humidity, etc. Considerable time is required to make observations of this kind since the establishment of conditions of equilibrium is ordinarily a slow process. The most troublesome factor is that of moisture content of the materials. Since moisture content is affected both by humidity and temperature, it was decided to show the effect of its removal by vacuum and heat treatment, on the conductivity of some insulating materials.

The method ordinarily employed in measuring volume resistance of insulating materials is to make the measurements between mercury electrodes provided with a guard ring. This method of testing during vacuum and heat treatment is clearly not suitable because of the evaporation of the mercury. Furthermore, the mercury would prevent the ready escape of entrapped air and moisture. To obviate these difficulties finely powdered graphite was tried for making contact between brass electrodes and the specimen, and this method proved not only suitable but better than mercury contact.

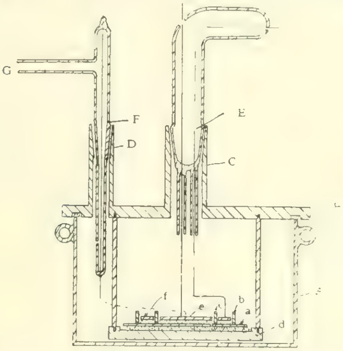

FIG. 1 DIAGRAM OF EQUIPMENT FOR VACUUM AND HEAT TREATMENT

The preparation of the sample and the method of making contact between the sample and the electrodes may be described as follows:—The sample *a*, Fig. 1 is a circular sheet of insulating material 3.5 inches in diameter. On the upper side of this sheet two cylindrical micarta rings *b* and *c* are fastened coaxially with shellac. These micarta rings are 1.75 and 3 inches inside diameter and one inch high with ⅛ inch walls. The lower electrode *d* was a circular brass disc four inches in diameter, so machined as to form a shallow tray 1/16 inch deep. This tray is filled with the powdered graphite and leveled to the rim of the tray with a straightedge. The lower surface of the sample is rubbed with powdered graphite with a soft brush and is then placed directly on the layer of graphite. The surfaces beneath the upper electrode and the guard ring are likewise rubbed with powdered graphite and then sprinkled with the graphite until the surfaces are entirely covered. The upper electrode *e* and the guard ring *f* are then put upon the graphite and pressed firmly into place. The resistance of the graphite, four or five ohms, is entirely negligible in comparison with that of the specimen. This method of making contact with the specimen is particularly suitable for observing the effect of heat and vacuum treatment on insulating materials because of the readiness with which gases and water vapor escape through the powdered graphite.

Fig. 1 also shows a diagram of the vessel in which the sample is given vacuum and heat treatment. *A* is an iron cylinder about six inches in diameter and five inches high. The upper end is closed by the brass plate *B* fitted with a rubber gasket. The leads to the guard ring and upper electrode are brought out through the ground glass stopper *E*. The lower electrode is in electrical connection with the plate *B*. A thermocouple for measuring the temperature at the under surface of the sample is brought out through the glass stopper *F*. The vessel is exhausted by a mercury diffusion pump connected at *G*. The specimen is conveniently heated to any desired temperature by placing the vessel on a small electric stove. The electrodes are so suspended from the top cover that the lower one, of considerable mass, rests upon the bottom of the vessel and insures a fairly even distribution of heat to the specimen. Water flowing through a copper tube soldered to the cylinder near the top prevents excessive heating of the gasket and ground joints.

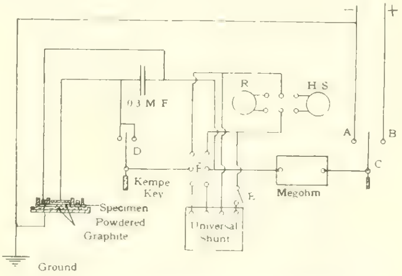

FIG. 2 THE ELECTRICAL CONNECTIONS

The electrical connections for direct-current resistance measurements are shown in Fig. 2. The galvanometers *R* and *HS* have a sensitivity of peres and 1 × 10^{-10} amperes respectively. The circuit is provided with a universal shunt so that from *1* to 0.0001 part of the total current can be measured by either of the galvanometers. A megohm resistance protects the galvanometers and is used in their calibration when the sample is short-circuited and a small known electromotive force is applied between *A* and *B*. With the switch *C* thrown on *B* and the switches *D* and *E* closed and the double-pole double-throw switch *F* thrown to the shunt, the conduction current can be read from the steady deflection of either galvanometer.

When the current through the sample is too small to produce a noticeable deflection of the galvanometer *HS*, the switch *F* is thrown directly to the galvanometer and switch *E* is opened. The condenser of 0.3 microfarads capacity is then charged by snapping the Kempe key *D* into the insulate position for a given time. The condenser is then discharged through the galvanometer ballistically by snapping the Kempe key into the discharge position. By calibrating the galvanometer by known quantities of electricity the current passing through the sample can be determined.

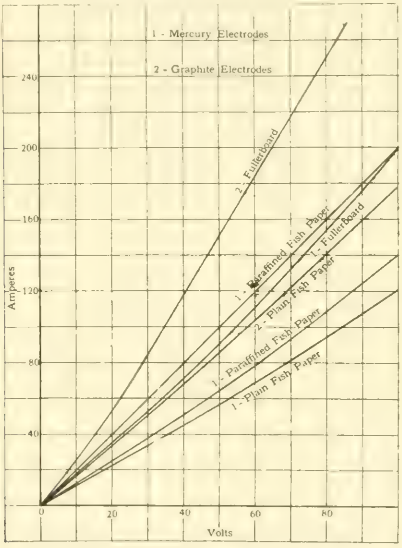

FIG. 3—THE EFFECT OF GRAPHITE AND MERCURY CONTACTS ON CONDUCTIVITY MEASUREMENTS

Tests on several samples of insulating materials with mercury and graphite contacts were made. In all cases better contact was made with graphite than with mercury. This is clearly shown by the curves in Fig. 3. This better contact is probably due to the fact that graphite fills the irregularities of the surface. In the case of mercury, air is no doubt entrapped in these irregularities because of the surface tension of the mercury and thus the effective area of the electrodes is decreased.

The materials tested in this work include fishpaper (untreated), paraffined fishpaper, fullerboard, and bakelite micarta. These were all of sheet material of varying thickness. The effective area of each sample was the same, being 12.5 sq. cm. To avoid the possibility of spark discharge at the reduced pressure the testing voltage was kept at 400 volts which is below the critical sparking potential for air.

The procedure carried out in testing these materials was as follows:—

1—Observation of decay current with time of application of voltage. This decay of current is common to all of the better insulating materials. In the poorer materials it is more or less masked by the true conduction current, in which case the current almost immediately reaches a steady value.

2—Change of current with time of vacuum treatment. By vacuum treatment moisture was removed, and the current which is affected thereby was correspondingly decreased. In general, if the material was loose and porous the moisture was readily removed and the conduction current was greatly lowered with time of vacuum treatment.

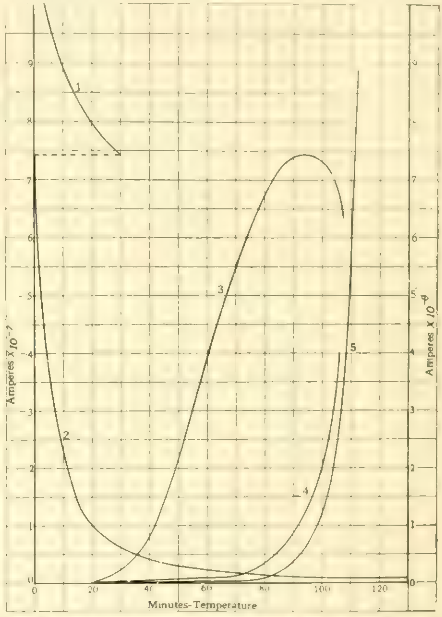

FIG. 4—CONDUCTIVITY OF UNTREATED FISH PAPER, 0.012 INCH THICK

In Figs. 4, 5, 7 and 8, curves *1* and *2* are plotted against time; curves *3*, *4* and *5* against temperature.

3—Observation of change in current when the specimen was subjected to heat treatment in addition to vacuum treatment. In all cases the heating was done at the same rate up to a maximum temperature of 105 degrees C. During this process two results were noticed. (*a*) The current was increasing greatly due to a temperature effect on the moisture in the material. (*b*) The moisture was continually being vaporized and removed by vacuum treatment. The effect of the latter was to lower the current until its final value was a very small part of the initial value.

4—Repetition of current temperature curves until the materials become stable during heat and vacuum treatment.

Fig. 4 shows the results obtained for fish paper (untreated), 0.012 inch thick. Curve *1* shows the decay of current over a period of thirty minutes. The rate of decay indicates that the steady value would not be reached for several hours. At the end of thirty minutes, vacuum treatment was begun and continued for about two hours. Curve *2* shows the effect of the vacuum treatment on the conductivity, which is reduced to a small part of its original value. At this point dry air was let into the system and allowed to stand over night. Measurements on the following morning showed that considerable curing action had taken place in the dry air during the night. After pumping to a good vacuum the specimen was given vacuum and heat treatment. Curve *3* shows a large increase of conductivity, reaching a maximum at about 95 degrees C, after which the curing action greatly decreases the conductivity. The effect on the conductivity of the first repetition of vacuum and heat treatment is shown by curve *4* whose scale of ordinates is shown at the right. Three further repetitions shown by curve *5* indicates that the conductivity has become stable with change of temperature at a slightly lower value than given by the first repetition in curve *4*.

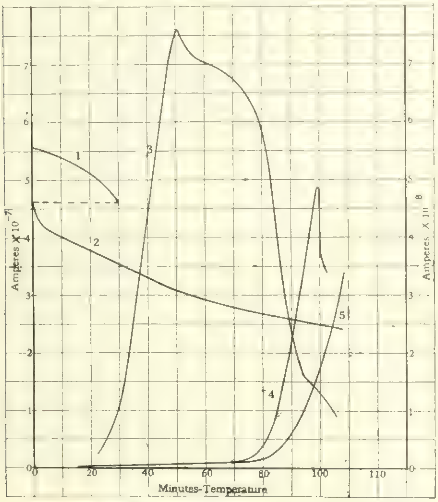

FIG. 5—CONDUCTIVITY OF PARAFFINED FISH PAPER 0.015 INCH THICK

Fig. 5 shows the results obtained with paraffined fish paper, 0.015 inches thick. The decay curve *1* is different from what is ordinarily obtained, having an entirely different change of slope. It would have been interesting to have observed this decay over a longer period of time had it not been that the next step in the treatment had taken place before this phenomenon had come to attention. Curve *2* shows that except for a short period at the beginning, moisture is removed with difficulty from this sample. In fact it is difficult to tell whether or not curve *2* might have been simply the continuation of curve *1*. Undoubtedly the treatment with paraffin tends to entrap the moisture in the material, preventing its ready escape. Curve *3* plotted on a scale reduced ten times shows enormous increase of conductivity with vacuum and heat treatment. A maximum conductivity was obtained at 50 degrees C, which is in the neighborhood of the melting point of paraffin. The decreasing part of this curve shows the form usually obtained during vacuum treatment. When the temperature has reached 105 degrees the conductivity is not greatly above that at the beginning of heat treatment. Curve *4* was obtained after the sample had stood over night in dry air, by repeating the vacuum and heat treatment. This curve also shows a maximum conductivity at about 99 degrees C, indicating that the curing action had not been complete.

Two further repetitions of vacuum and heat treatment gave results quite different from curve *4*. Upon further treatment the material suddenly underwent a change, giving much larger changes of current with temperature, but again reached steady conditions, as shown by Fig. 6 for three further successive repetitions. The conductivity when cold, however, was not greater than previously. This behavior is no doubt due in some way to the melting of the paraffin with which the fish-paper was impregnated.

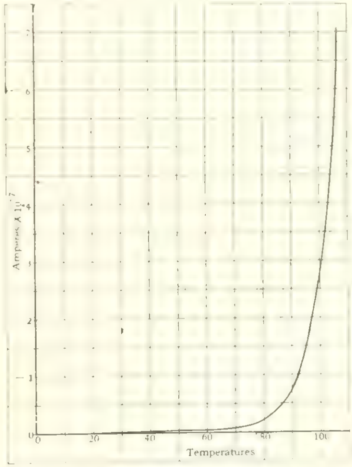

FIG. 6—CONDUCTIVITY OF PARAFFINED FISH PAPER AFTER FIVE REPETITIONS OF VACUUM AND HEAT TREATMENT

Fig. *7* shows the results obtained with fullerboard (untreated) 0.030 inch thick. Curve *1* shows that the decay curve reaches an almost steady value after one hour. Curve *2* shows that moisture is readily removed from this porous material, vacuum alone reducing the conductivity to a small part of the original value. Curve *3*, the value of the ordinates being given at the right, shows that heat treatment after vacuum treatment has a minor effect. There is, however, a decided maximum at about 60 degrees C after which the conductivity decreases due to the given treatment. The minimum also obtained at 90 degrees C in this curve is due to true temperature rise after the curing of the material. Curve *4* is for the first repetition after standing in the usual way. Curve *5* is for further repeti tions and the results show that the material has reached a steady state under heat and vacuum treatment.

Fig. 8 shows the results obtained with bakelite micarta, 0.015 m thick. A slow change of current with time is shown by curve *1*. This material is rather hard and closely pressed. That moisture is removed rather slowly is shown by curve *2*, considerable change still taking place after 104 minutes. Curve *3* with values of the ordinates as shown at the right, shows enormous evolution of moisture and, probably, solvents, the conductivity reaching a maximum at about 92 degrees C. After this temperature is reached the conductivity decreases, due to the curing of the material. At 108 degrees C the heater was disconnected and the sample was allowed to cool. The lower part of the curve shows the decrease of conductivity with temperature. After standing in the usual way over night there was no further increase of conductivity with temperature up to 108 degrees but on the contrary a small decrease. This indicates that the curing action was still going on and that the temperature effect was practically negligible with the instruments used.

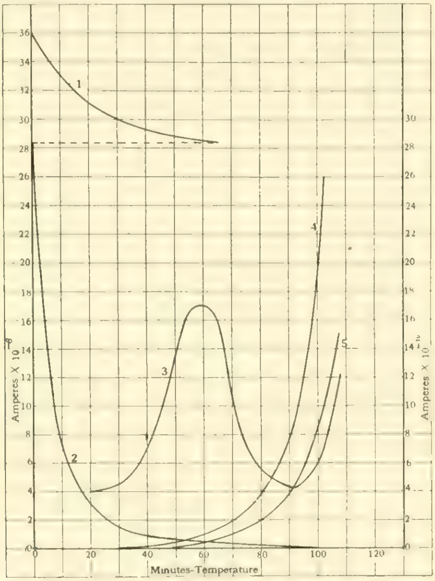

FIG. 7—CONDUCTIVITY OF UNTREATED FULLERBOARD 0.030 INCH THICK

Enough work was done to realize that the sensitivity of the apparatus used was scarcely sufficient. The effect of the treatment given made the conductivity of the materials so small that at room temperature it was measurable only with difficulty and great accuracy could not be depended upon. Suffice to say that the smaller currents were not larger than recorded, though how much smaller could not be ascertained with the instruments used. To extend the range of measurement a combination of the galvanometer and electrometer methods is to be used in future work.

To indicate numerically the changes which have taken place during treatment of these samples Table I has been prepared. It should be stated however that the curing action on Bakelite micarta had not reached completion. In this table the following symbols are used:—

r = apparent resistivity at room temperature, 22 degrees C.
r_v = apparent resistivity after vacuum treatment.
r_{v+h} = apparent resistivity after vacuum and heat treatment.

TABLE I—EFFECT OF VACUUM AND HEAT TREATMENT ON RESISTIVITIES

Material	r	r_v	r_{v+h}	$\frac{r_v}{r}$	$\frac{r_{v+h}}{r}$
Fish paper (untreated)	13×10^{10}	14.2×10^{12}	8.09×10^{15}	109	62000
Paraffined Fish paper	23.4×10^{10}	6.22×10^{11}	6.5×10^{16}	2.66	278000
Fullerboard	17.4×10^{10}	16.2×10^{13}	32.4×10^{15}	93.0	186000
Bakelite Micarta	25.7×10^{10}	27×10^{12}	8×10^{14}	10.5	310

CONCLUSIONS

The work done in this investigation indicates very clearly the part that moisture plays in the electrical conductivity of insulating materials. This moisture can readily be removed by vacuum and heat treatment, during which treatment its progress can be followed by electrical measurements. One might easily conceive the idea that conductivity in this class of materials depends largely upon the amount of moisture present for dissociation, by which means only conduction can take place, and that the insulating properties of a dielectric depend largely upon its tendency to absorb moisture. In other words it would indicate that insulating materials might be classified electrically by their hygroscopic properties.

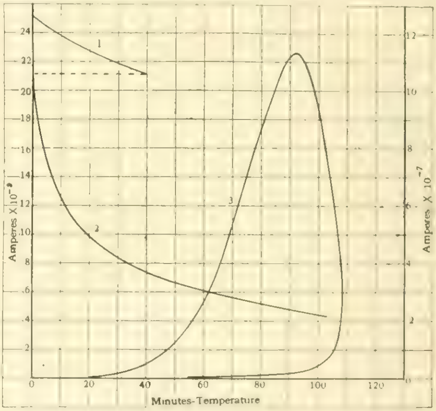

FIG. 8—CONDUCTIVITY OF BAKELITE MICARTA 0.015 INCH THICK

It is noticed that most of these materials tested become very good insulators after the treatment given. This property is not altogether permanent when the materials are again exposed in a humid atmosphere. Measurements as to rates of deterioration have not as yet been made but a completion of the work is contemplated along this line.

The Relations Between Gases and Steel

H. M. Ryder

OWING to the tremendous importance of the effects of gases of various kinds on iron and steel, many efforts have been made during the past sixty years to determine just what chemical and physical relations do exist, and to what extent these may be modified in order to develop steel of higher or more uniform quality. One of the important contributions to the steel industry in this line of effort was the practical elimination of blow holes from steel ingots by Sir Henry Bessemer. The use of "deoxidizers" in steel manufacture is an example of the advantages to be obtained from the application of the principles involved in this subject. Case hardening is another process which depends, for its success, upon interactions between gases and steel. It is not surprising, then, that probably eighty papers have been published, giving accounts of experimental and theoretical effort to increase our knowledge of the phenomena involved.

In October, 1918, a general conference on this subject was held in England, under the direction of the Faraday Society, and their published record, together with a bibliography announced by them*, forms a very complete history of this subject. The outstanding feature in this literature is the fact that, although considerable qualitative data has been obtained, and many "rule of thumb" methods have been developed concerning the interaction of gases and steel, very little work of a quantitative nature has been done. The reason for this at once presents itself when the difficulties of the problem are considered. A quantitative study of chemical, or pseudo-chemical reactions, where one or more of the constituents is a gas, and is a very small percentage of the whole, is itself a tedious undertaking, but when added to this, is the fact that much of the work must be done at temperatures ranging from 500 to 1700 degrees C, and in pressures less than 0.001 mm of mercury (one millionth of an atmosphere), the difficulties are many times multiplied.

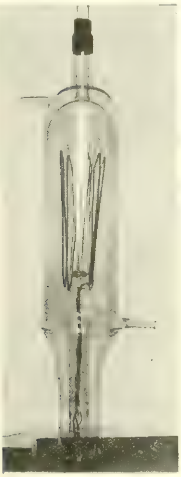

FIG. 1 DOUBLE WALLED GLASS SPECIMEN BULB

Used in tests for the determination of the evolution of gases from steel.

For a long time, a number of these difficulties appeared insurmountable, but owing to the great advance made in recent years in electrical and vacuum apparatus, much of this work has been brought within the range of possibilities, and some valuable information has already been obtained. Among the items which have contributed largely to the possibility of this work, a few will be considered here.

The use of a "hard" glass, of high softening temperature and low coefficient of expansion is used in extensive systems for the control and study of gases associated with the steel under examination. The well known "soft" or "soda" glass would be far too fragile for this work, and further does not lend itself to the sealing through of electrical conductors of sufficient current carrying capacity. In one system, all of glass, there are over two hundred feet of tubing, and having an approximate volume of twenty-five liters. Electrical conductors, having a current carrying capacity in excess of one hundred and twenty-five amperes, sealed through glass walls in a vacuum tight manner are in use. The mercury diffusion vacuum pump, introduced by Gaede[1], and greatly improved by Langmuir[2], Shrader[3] and others has made possible the handling of minute quantities of gas without fear of loss or polution. A third important development consists of an apparatus for the quantitative analysis of small quantities of gases[4], by means of which one or two cubic millimeters of gas can readily be analyzed with an accuracy of 95 percent or greater. With the assistance offered by this and other apparatus of recent origin, the work described in this paper was made possible.

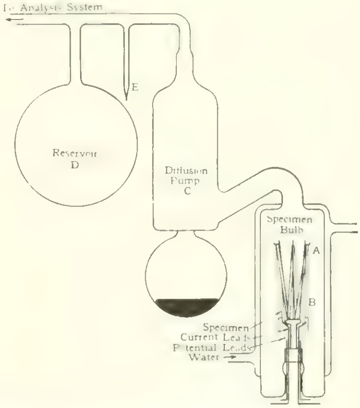

FIG. 2 DIAGRAM OF EQUIPMENT FOR REMOVING AND COLLECTING GASES FROM METALS

The plan for the present work on the fundamental relations between gases and steel provided for three forms of experiment. The first of these consists in the determination of the contained gases in steel, the temperatures at which these can be evolved, their rate of evolution, and the quantity found. The second concerns itself with the diffusion of gases through metal, the absolute rate of this diffusion and its variation with the temperature, and the effect of the steel on the composition of the gas which may diffuse through. The third provides for the effect of various atmospheres on steel at different known temperatures. Certain results which have been obtained, in pursuance of this program, and which appear to be of general interest follow. Consideration will be given here to temperatures below 1000 degrees C only.

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*Transactions Faraday Society, February 1919.

[1] —Gaede, *Ann. d. Phys.* Vol. 46, p. 357, 1915.

[2] —Langmuir, *Phys. Rev.* N. S. Vol. VIII, p. 48, July 1916.

[3] —Shrader and Sherwood, *Phys. Rev.* N. S. Vol. XII, p. 70, July 1918.

[4] —Ryder, *Jour. of the Amer. Chem. Soc.* Vol. XI, p. 1656, Nov. 1918.

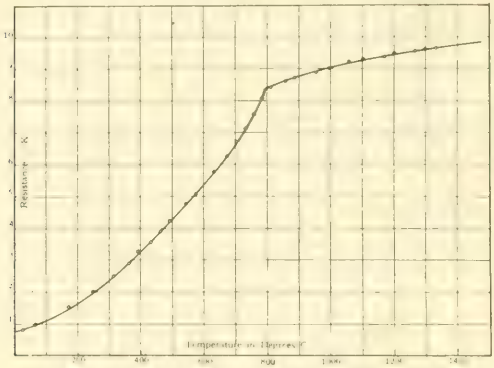


FIG. 3—RELATION BETWEEN ELECTRICAL RESISTANCES AND TEMPERATURE FOR PURE IRON (CARBON APPROXIMATELY 0.01 PERCENT)

For the determination of the evolution of gases from steel, the specimen is prepared in the form of a strip, and mounted on tungsten supports in a double walled glass tube. The strip is so connected electrically that it may be heated just as a tungsten filament is in an ordinary lamp, with the addition of potential leads for temperature measurement. Fig. 1 shows one of these tubes ready for a test. Circulating water passes between the two walls of the tube, and keeps the glass cold, so that the only hot portion of the outfit is the specimen itself This tube is sealed to a glass diffusion pump and a gas collecting reservoir, as shown in Fig. 2, and the whole connected to the system for gas analysis referred to above. In operation, the highest possible vacuum is maintained in the specimen tube, all gas upon release being immediately pumped into the reservoir and held there until ready for analysis. It is customary to maintain the specimen at a constant temperature for twenty-four hours, at the end of which time the gas is removed for analysis and the temperature of the specimen is raised 50 degrees C and similarly held for the succeeding twenty-four hours. This procedure is repeated until the specimen fuses at some point. As the iron begins to vaporize rapidly at 900 degrees C, and any "hot spots" which develop, therefore, tend to increase, due to the cumulative effects, it is often not possible to run the temperature much higher than 1100 degrees C.

The temperature is determined by measuring the ratio of the hot resistance to the resistance at zero degrees, C. The relation between these ratios and the temperature is determined in advance on a piece of the same specimen material in a tube furnace with a thermocouple. Fig. 3 shows a curve obtained in this manner. The temperatures above 700 degrees C are further checked by the use of the radiation law, the constants for which have been determined at lower temperatures. This is necessary, owing to the small slope of the curve above the critical point.

The results of experiments performed in accordance with this plan, on two different types of steel are shown graphically in Figs. 4 and 5. The material considered in Fig. 4, is a commercial silicon steel and in Fig. 5 a vacuum fused "pure" iron, prepared in the laboratory. Both of these specimens had been subjected to various known forging and heat treatments, both of which tend to modify the results as found. Several conclusions can be drawn, however, from the curves here shown, corroborated by many other similar ones. These may be listed as follows:

1—Oxygen appears only at 250 degrees C and there in small quantity.

2—Nitrogen appears at approximately 700 to 800 degrees C and in varying limited quantities.

3—Hydrogen appears at about the same time as nitrogen, but in indefinite quantities. In addition very small amounts are liberated at lower temperatures.

4—Water is liberated below 200 degrees C. The water curve is not shown in Fig. 4.

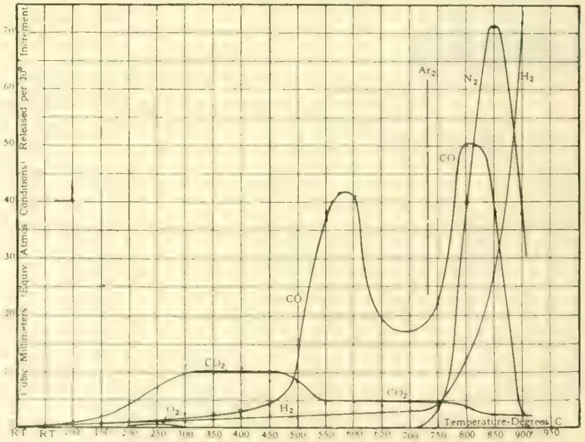


FIG. 4—EVOLUTION OF GASES FROM COMMERCIAL SILICON STEEL

5—Carbon dioxide is liberated principally in the neighborhood of 300 degrees C.

6—Carbon monoxide is released in three periods, at approximately 300 degrees C., 600 degrees C., and at 800 to 900 degrees C.

7—Other gases are present only in negligible quantities.

Experimental work on the rate of evolution of these gases shows that, in general, this value at constant temperature is reduced to one-tenth of the original value at the given temperature in less than six hours in the case of water, carbon dioxide and the 300 degrees C., hump of carbon monoxide; in less than twenty-four hours in the case of the 600 degrees C. hump of carbon monoxide; and only after sixty hours in the case of hydrogen, nitrogen and the 800 degrees C. hump of carbon monoxide.

For the determination of the rate of evolution of gases through a steel wall, an apparatus of the form shown in Fig. 6 was used. The specimen here is in the form of a seamless steel tube, closed at one end, with the other end sealed to a vacuum measuring and analysis system. This tube is located concentrically with a silica tube, and the whole inserted in a tube furnace as shown. Provision is made for maintaining any desired atmosphere at slightly more than one atmosphere of pressure in the space surrounding the specimen tube, so that, with a vacuum on the interior, the gas must pass through the wall of the tube under test. Since the temperature distribution is not uniform, the results must be approximate, but by making certain obvious corrections, values of sufficiently close approximation to the true ones are obtained. For precision work, this apparatus is slightly modified.

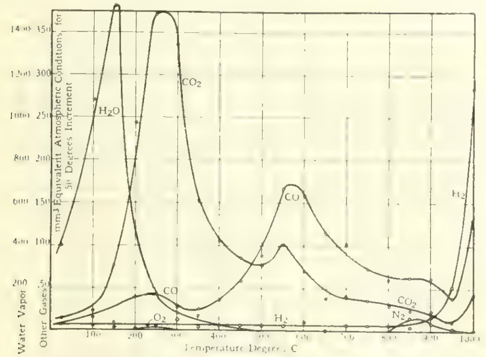


FIG. 5—EVOLUTION OF GASES FROM VACUUM FUSED PURE IRON

In the operation of this apparatus, the interior of the specimen tube is highly exhausted, and the whole heated to 600 degrees C. to eliminate surface sources of gases. After returning to room temperature, the gas to be used is introduced in the annular space surrounding the specimen tube and, throughout the test, is kept slowly circulating. The temperature of the furnace is increased at a constant rate of approximately one degree a minute from room temperature to 1100 degrees C, or as near that temperature as seems desirable. During this period, pressure readings are made on the system connected with the interior of the tube at five minute intervals. The pressure thus determined is a measure of the total quantity of gas which has entered the system through the wall of the tube, and the curve obtained is one of total quantity against temperature. The slope of this curve at any point will be proportional to the rate of diffusion of the gas, and the rate curves are therefore plotted accordingly. The curve labelled *Time* in Fig. 9 indicates the degree to which uniformity in the increase of the temperature of the furnace may be maintained, and the *Quantity* curve the actual result of experiment, in this case for nitrogen. The identity of the gas which diffused through the steel was determined by analysis.

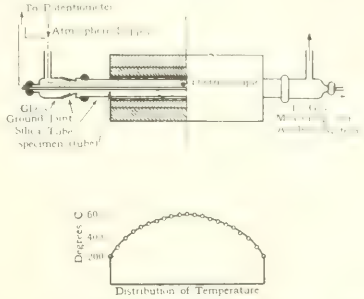


FIG. 6—APPARATUS FOR THE DETERMINATION OF THE DIFFUSION OF GASES THROUGH METALS

Fig. 7 shows graphically the effect of the temperature on the rate of diffusion of several gases through a steel wall. In the cases shown, no resultant chemical reaction takes place except for carbon monoxide at temperatures above 950 degrees C. In this case the carbon associates itself with the steel and case hardening results. The relation between the rate of diffusion of the gas and the corresponding temperatures is shown in Fig. 8. This is a general condition for gases when no chemical reaction takes place, but in most cases, the slope changes abruptly when passing through the critical point. Carbon dioxide and a number of other gases

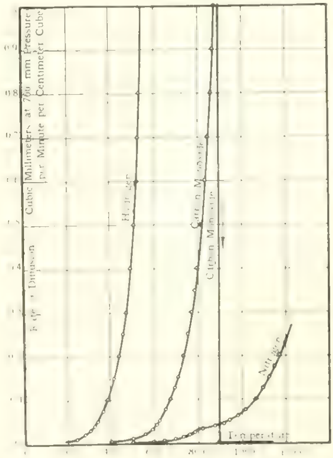


FIG. 7—EFFECT OF TEMPERATURE ON THE DIFFUSION OF HYDROGEN, CARBON MONOXIDE AND NITROGEN THROUGH MILD STEEL

will not pass through steel without decomposition. Argon will not pass through at any temperature up to 1100 degrees C.

For the study of the effects of the various atmospheres on steel at elevated temperatures, the specimen is prepared in the form of a long strip and mounted as in the experiments first described, Fig. 2, except that no pump is placed in the system. The desired atmosphere is introduced into the tube, and so arranged that pressures may be readily noted, and corrections applied due to the hot portions. Ordinarily, when a specimen is put under observation, it is first freed as far as possible of all gases by being held at 900 degrees C for several days in a high vacuum. The atmosphere under consideration is then introduced, with the specimen cold. With the temperature of the specimen being increased from time to time, using fifty degree increments, the condition of the metallic surface is carefully observed, as is also the pressure. At convenient times samples of gas are drawn off for analysis. After the highest safe temperature is reached, the specimen is again brought to room temperature, and the surrounding gases removed. With the vacuum maintained, the specimen is again heated, using fifty degree increments, and gaseous evolutions observed and analyzed. In some cases various maximum temperatures are used on a series of specimens, and the chemical and micro-analyses of specimens determined.

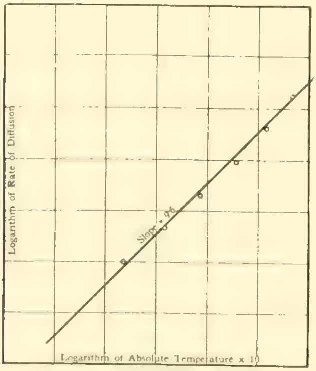


FIG 8 THE DIFFUSION OF HYDROGEN THROUGH MILD STEEL

As a result of this work, the following results are among those obtained, it being understood that the accuracy of the results should be considered in the light of the precision of the method, and that the limiting temperature is 1000 degrees C.

Dry nitrogen has no effect on the steel, and is not adsorbed.

Dry carbon dioxide does not appreciably react in this sense with the steel, but is adsorbed on the surface.

Hydrogen does not react with the steel.

Carbon monoxide does not react at temperatures below 900 degrees C, but above this it decomposes, the oxygen forming a surface oxide, and the carbon entering the steel.

Cyanogen reacts at 650 degrees C, a portion of the nitrogen and carbon entering the steel, more of the carbon being deposited on the surface, and a certain amount of nitrogen freed. The nitrogen entering the steel combines chemically with it and may be freed upon subsequently heating the steel in vacuum.

Ammonia reacts with steel at approximately the same temperature, nitrogen and hydrogen entering the steel and individually combining chemically with it. A portion of the ammonia is also dissociated without reaction with the steel. The hydrogen and nitrogen may be taken from the steel in the ratio of 3 to 1 by heating in vacuum to 900 degrees C.

As a result of the experimental work done on the interaction between gases and steel, some of which is reported here, the conditions involving each of the ordinary gases can be fairly well defined, for temperatures between zero degrees C and 1000 degrees C (for the purpose of this paper). In the following resume, each gas will be considered in order.

Water vapor does not exist, as such, in the interior of steel, but is adsorbed on the surface.

Carbon dioxide does not exist in the interior of steel, but is adsorbed on the surface. The hump in the carbon dioxide curve at 300 degrees C is due to the burning off of organic material, such as grease. The size of this hump is dependent on the thoroughness of the cleaning of the material, and not on the material itself. Fig. 5 shows the effect of no cleaning, as compared with the effect of the thorough cleaning shown in Fig. 4. Copper, porcelain, and several kinds of glass were tried, for a comparison of this point, and the hump was found to be independent of the material.

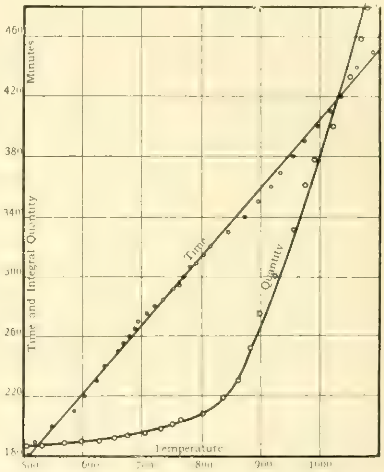


FIG. 9 THE DIFFUSION OF NITROGEN THROUGH MILD STEEL

Carbon monoxide, as exemplified in the first hump, at 300 degrees C, is also a result of the combustion of the grease. The second hump, at 600 derees C is the result of the dissolved or entrapped gas diffusing out. This is evident from the fact that 600 degrees C is the temperature at which diffusion becomes appreciable, and also because carbon monoxide is not formed nor dissociated, relative to iron, at this temperature. Further, if it were adsorbed material, it would be released at a lower temperature. The third hump in the carbon monoxide is due to the formation of this substance as a result of the combination of the carbon contained in the steel and the oxygen to be found in the scale. The amount of gas formed here is limited by reason of the small quantity of oxygen available and is therefore no measure of the carbon content of the steel. The theory of this reaction is verified in the experimental work described. since the temperatures concerned are those at which iron is carbonized in the presence of an excess of carbon monoxide, and at which carbon monoxide is formed from carbon containing iron in the presence of available oxygen. A true carbon determination should not include the carbon released as carbon dioxide, or carbon monoxide at temperatures below 700 degrees C, since this carbon plays no part in the physical characteristics of the steel. This, of course, is a factor of much greater importance in a consideration of the very low carbon steels.

Oxygen does not exist in steel, as such. The only oxygen which was found by the methods described in this report was released at 250 degrees C and coincided with the temperature at which a small amount of a red oxide on the surface of the steel turned black. The oxygen found is no doubt the result of this reaction in the very low pressure of the tube.

Nitrogen is not evolved below the critical temperature, but comes off readily above that point. This is the result of chemical decomposition, as dissolved or entrapped nitrogen should be evolved at approximately 600 degrees C. Since no trace was observed at this temperature it is probable that in rolled steel there is no free nitrogen present.

Hydrogen is evolved when the steel is heated in a vacuum, in general in very small quantities at all temperatures up to the critical temperatures, beyond which it is released in large quantities. This release is due to the breaking down of a compound as in the case of nitrogen and not to dissolved hydrogen. The small continuous evolution of hydrogen is no doubt due to the slow decomposition of the hydrogen containing constituent. This phenomenon is observed in pickled steel which, upon being aged at room temperature, gradually loses its brittleness, this condition being simultaneous with the loss of hydrogen.

Methane is present in steel in isolated cases, and then only in very small quantities.

The total volume of the evidence obtained in favor of the conclusions here given is much too great to be presented in this paper, but it is believed that all of the essential conditions have been discussed at sufficient length to show justification for the statements given. The consideration of this problem for high temperatures involves an entirely different type of apparatus and forms a separate subject for discussion. I am much indebted to Mr. C. E. Sperow for his assistance in carrying through this arduous program.

Stroboscopic Slip Determination

M. M Bries

IN CALCULATING the performance of induction motors, the percent slip is an important element. By definition, the slip is the difference between synchronous and actual speeds. Its determination by subtraction is difficult, especially where the frequency is subject to slight fluctuations, as a small error in the measurement of either speed will produce a large percent error in the slip. For this reason a means of measuring slip directly is desirable, the stroboscopic types of slip meters being in most common commercial use.

The simplest type of slip meter consists of a white disk, having the same number of black sectors as the motor has poles, mounted on the shaft of the motor under test, as shown in Fig. 1. This is viewed in such a way that the vision is interrupted periodically in synchronism with the alternations of the circuit. Then, due to the continuity of vision of the eye for light impulses exceeding about 15 per second, when the painted disk is rotated at synchronous speed, it appears to stand still. This is because, at each instant of vision, a black sector has assumed the exact position of the one ahead of it at the last previous glimpse. When, however, the painted disk is driven below synchronous speed, as is usual with induction motors, the black sectors do not move through a complete polar division during one alternation. Therefore, at each glimpse, the black sector is slightly behind the position of the last one previously seen, producing an apparent backward rotation, which corresponds to the difference between the synchronous rotation and the actual rotation; in other words, the slip. This number, multiplied by 100 and divided by the synchronous speed, gives the percent slip.

There are two common methods of producing the interruptions of vision. The first, shown in Fig. 1, consists in looking through a disk, driven by a synchronous motor, and having the same number of slots that the observed disk has painted sectors. The second consists in viewing the painted disk by the light from an alternating-current carbon arc lamp, whose light fluctuates in synchronism with the alternations.

A variation of the above methods, devised by Professor Perkins, of the University of Tennessee, consists of a disk mounted on the shaft of the motor under test, and provided with a narrow slot. Behind the disk is mounted a vibrating steel reed, actuated by a magnet connected to the same circuit as the motor. The reed is weighted to make its natural period of vibration the same as the frequency of the motor supply current.

With the reed vibrating and the motor running at synchronous speed, it is apparent that the reed will be in the same position each time a glimpse of it is obtained through the rotating slot. Hence it will appear stationary. But when the rotor lags behind synchronism, the reed will appear to vibrate slowly, a complete vibration corresponding to one revolution which the motor has dropped below synchronous speed. As it is possible for such a reed to vibrate at some multiple of the supply frequency, this device should be calibrated experimentally before use.

All of these devices are quite satisfactory for measuring low slips, but are limited by the ability of the tester to count the apparent rotations or oscillations. It has been found by numerous trials with various individuals that, by taking the time with a stopwatch for 100 oscillations, a rate of 150 oscillations per minute, could be counted with an error of not more than two-fifths of a second. With a 60 cycle, four-pole motor, 150 apparent oscillations per minute corresponds to 2.08 percent slip. As a large proportion of induction motors are built for 60 cycle operation and have a percentage slip varying from two to eight percent or more, the use of these devices is very limited in testing commercial apparatus.

To overcome this practical objection, a modification of the vibrating reed slipmeter has been devised by Mr. G. Jensen, of the Westinghouse Company, by which it is possible to obtain accurate measurements of slips ranging from zero to ten percent or more. The device, as used in commercial tests, consists fundamentally of two parts, the electromagnetic vibrator and the slotted disk, arranged so as to be driven at various speeds, through a set of gears, from the shaft of the motor under test.

The improved device is simple in construction and accurate over a wide range of application. The electromagnetic vibrator comprises a magnetizable core member *8*, a winding *9* and a resilient armature or reed *10*, as shown in Fig. 2. The effective length of the armature or reed is adjustable, so that its natural period of vibration coincides with the frequency of the alternating current that passes through the magnetic winding. Marks on the reed indicate the 25 and 60 cycle positions. Positions corresponding to other frequencies may readily be obtained by shifting the reed up and down until the vibrations become normal. As the magnet and its accompanying lamp are adapted for 110 volts only, a suitable transformer must be used in connection with higher voltages. A standard voltage transformer is perhaps the most convenient to use for this purpose. As this type of transformer is loaded quite close to its rated output by this device alone, it should never be depended upon to operate other instruments at the same time.

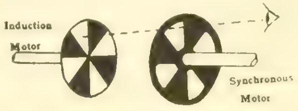


FIG. 1—SIMPLE TYPE OF SLIPMETER

The gear box consists of a set of gears by means of which the slotted disk may be driven at various ratios with respect to the speed of the motor under test. A universal coupling connects it with the motor shaft through a connecting piece screwed into its center. Both the gear box, and the vibrating reed are adjustable vertically on the supporting rod. After the gear box has been lined up with the motor shaft, the vibrator is dropped down until the reed can be readily seen through the radial slots in the rotating disk, as shown in Fig. 3. In making the connection to the motor shaft, the pin in the flexible shaft should be about in the center of the slot so as to allow for end play on starting the machine. In inserting the connecting pin into the driving part of the coupling, the knurled sleeve should be grasped firmly and pressed gradually into the opening until it is felt to slide into place. The coupling is readily separated, while in operation, by a firm pull on the knurled sleeve.

The disk may be driven direct or through the gears, depending on the pinion to which the driving shaft is connected. The spindles of these pinions are marked 0, 4, 8. The numbers indicate the percent slip at which the vibrating reed will apparently stand still when the disk is driven from them.

The disk is provided with oppositely disposed radial slots, the number of which is an integral factor of the number of poles of the motor. With this apparatus, five disks are furnished, as follows:—

2 slot disk is to be used with 2 and 4 pole machine
6-slot disk is to be used with 6, 12 and 18 pole machine.
8-slot disk is to be used with 8, 16 and 24 pole machine.
10-slot disk is to be used with 10, 20 and 30 pole machine.
14 slot disk is to be used with 14 and 28 pole machine.

While a single slot disc can be used with any number of motor poles it is obvious that the vibrating image will be clearest when the number of slots is equal to the number of poles of the motor. The number of slots may be any sub-multiple of the number of poles.

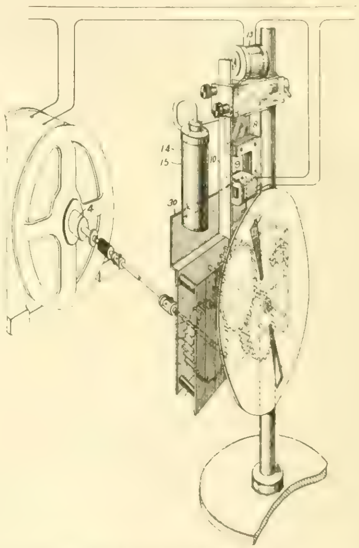


FIG. 2—MODIFIED VIBRATING REED SLIP INDICATOR

With the disk driven direct and with the motor running at synchronous speed, it is evident that a view of the reed, when the latter is properly adjusted, will be obtained a certain number of times a revolution and if the number of radial slots in the disk is an integral factor of the number of poles of the motor, the reed will be seen in the same position each time, or in other words it will apparently stand still. However, if the motor is operating at a speed slightly lower than synchronism, the reed will be found in a slightly different position at each view and it will apparently oscillate from side to side like a pendulum. Since a properly adjusted, unpolarized reed vibrates in synchronism with the circuit, the apparent oscillations of the reed will correspond to the alternation slip. The effect will be the same whether the speed of the disk is above or below synchronism. Then the rate of the apparent oscillation of the reed is a definite measure of the slip and it is preferable to consider the slip in terms of alternations rather than in r. p. m. On this basis, the apparent vibrations per minute will be equal to the alternation slip per minute. Therefore if,—

v = Actual vibrations of the reed or the alternations of the circuit per minute.
a = Apparent oscillation of reed per minute.
p = Number of poles of motor.
r = R.p.m. of motor.
s = Slip in percent.

Then $$s = \frac{100\,a}{v}$$

and $$r = \frac{v}{p} - \frac{a}{p}$$

In order to obtain an accurate count of the apparent oscillations of the reed a definite number of oscillations should be counted, the time t in seconds being noted.

Let a' = *apparent oscillations in t seconds*

then $$s = \frac{100 \times 60\,a'}{v\;t}$$

and $$r = \frac{v}{p} - \frac{60\,a'}{p\,t}$$

As the percent slip increases, the number of apparent oscillations increases to such an extent that it will be impossible for the tester to count the number of apparent oscillations of the reed. When the disk is driven from the spindle marked *4* it is speeded up and will revolve faster than the motor, thereby, reducing the number of apparent oscillations of the reed. The reed will apparently stand still with this connection when the motor has exactly four percent slip, instead of at zero slip as when direct connected. This value then may be taken as a new point of reference and the slip in alternations, up to 150 per minute, may again be counted. As previously noted, this slip may be either higher or lower than that of the reference point. The gear ratio c of the four percent and eight percent spindles are 0.96 and 0.92 to 1 respectively. Therefore, if

c is the gear ratio (less than one),—

then $$s = 100\left(1 - c \quad \frac{a}{v}\right)$$

and $$r = c\;(v/p \quad a/p)$$

If the apparent vibrations increase as the motor load is increased use the + sign. If they decrease, use the — sign.

The synchronous reed, while its vibration is essentially forced, has a decided advantage over a tuning-fork in making slip measurements in that only the nominal frequency of the driving current need be known to determine v. With the tuning-fork it would be necessary to know the actual frequency, since the speed of the motor under test would vary with either load or frequency or both. In using a tuning-fork the same formulas may be used if p equals the number of pairs of motor poles.

Table 1 summarizes the application of the slip indicator under various conditions that are ilkely to arise in commercial practice.

TABLE I—SLIP INDICATOR SETTINGS

Percent Slip	0-2		2-4		4-6		6-8		6-10	
Frequency	25	60	25	60	25	60	25	60	25	60
Spindle	0	0	0	4	4	8	4	8	8	8
Max. Reading	60	144	120	144	120	144	120	144	60	144

The following general formulas are found convenient in practical testing:—

At 25 cycles the percent slip = marking of pinion ± $\dfrac{100}{\textit{time in sec. of 50 oscil.}}$

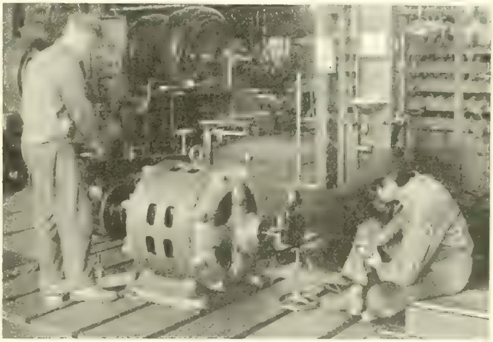


FIG. 3—MEASURING SLIP OF INDUCTION MOTOR UNDER LOAD
With vibrating reed slip indicator.

At 50 cycles the percent slip = marking of pinion ± $\dfrac{100}{\textit{time in sec. of 100 oscil.}}$

At 60 cycles the percent slip   marking of pinion $\dfrac{83}{\textit{time in sec. of 100 oscil.}}$

$$R.p.m. = \frac{\textit{alternations per minute (rated frequency)}}{\textit{number of poles}} \times (1 - \textit{percent slip})$$

With the improved vibrating reed slip indicator, it is never necessary to count higher than 144 vibrations per minute. It has been found rather difficult to count the oscillation accurately when they fall below 20 per minute, therefore, it is best to change the connections to the spindle when readings are obtained which are too close to synchronism.

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

APRIL 1920

Method of Connecting Car Wiring to Motor Leads and Ground

Numerous failures and delays of cars in service are caused by open circuits in the motor leads, due to one or a combination of the following causes

a—The lack of or improper use of cleats on motors and car

b—Placing the knuckle joint connectors in the swinging loop between car underframing and motor.

c—Motor leads too short to allow full swing of truck.

d—Insufficient flexibility of cable.

e—Improper method of supporting cables from car underframing and at motor.

Cables which are allowed to swing from the point at which they issue from the motor housing are continually rubbing back and forth over the top of the motor as the car negotiates various curves and crossovers. This continued friction between the leads and the rough motor frame soon wears away the cable insulation and failure occurs, due to grounding of the leads on the motor. Failures due to this method of suspension of motor leads involves a great amount of work, due to bringing out of new leads, should the breakdown of cable insulation occur at the point where the cables issue from the housing.

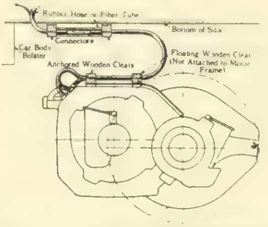

Rubber Hose or Fiber Tube
Bottom of Sills
Connectors
Car Body Bolster
Anchored Wooden Cleats
Floating Wooden Cleat (Not Attached to Motor Frame)

FIG. 1—METHOD OF CABLE SUSPENSION

Which has been used with considerable success by large operating companies.

On installations which have the connectors placed in the swinging loop, the cable has a tendency to break at the point where it is soldered into the connector, due to the hard spots in the cable where the strands are soldered together. There is also the possibility of poor insulation at this point, as the operator through carelessness and other causes, is apt to use insufficient amount of insulation. This may give rise to grounds and probably open circuits, due to the insulation coming off entirely, and the knuckle joint connector breaking in two.

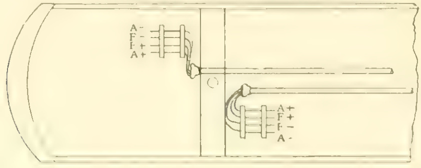


FIG. 3—SEQUENCE OF LEADS AT CLEATS ON CAR UNDERFRAMING

On roads having very sharp curves, the swing of the motor trucks is considerable. The motor leads, while being of sufficient length to negotiate the curves, are not always long enough to assume the proper loop under the extreme curve conditions. Where this occurs, the cables are strained and their life shortened to such an extent that failures are encountered.

With cables having large size individual wires and a few strands, the loop between the car underframing and the motors would not lie in the proper position. This is due to the stiffness of the cable which, under the force of gravity, does not assume a small enough radius of curvature at the bend. The cables under these conditions fatigue very easily and breakage of strands occurs, giving rise to failure of the leads.

Probably one of the most serious defects is encountered at the point where the cables drop down or swing from the car underframing. In some cases, the cables are dropped at a point too near or too far away from the truck bolster, and in others the method of supporting the cables where they leave the conduit at the car underframing is poor.

REMEDY FOR TROUBLES

A scheme of connections and cable suspension which has been used with considerable success by a number of operating companies is shown in Fig. 1, which illustrates the method employed for inside hung motors; for outside hung motors, the general arrangement is practically the same. The knuckle joint connectors are held firmly in place between two cleats fastened to the car underframing. The cleats holding the connectors should be placed as near as possible to the bolster and the truck pin on the car underframing. This is done in order to keep the length of the cable loop, as it swings between the car underframing and the motor, as close to its original length as possible in any position of the truck, relative to the car. About three inches should be allowed on either side of the connector between the cleats to take care of creepage. The cleats are split so that they can be put in place after the connections have been made and the insulating hose or tube has been slipped over the connectors.

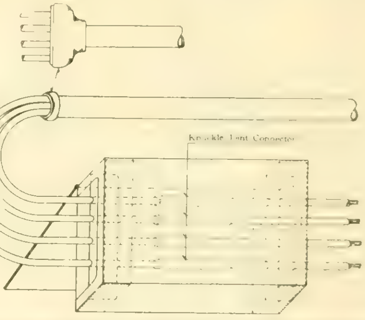


FIG. 2—JUNCTION BOX FOR KNUCKLE JOINT CONNECTORS

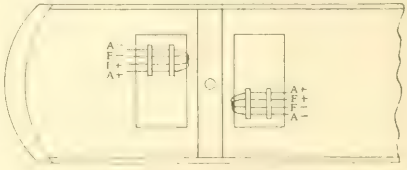


FIG. 4—SEQUENCE OF LEADS AT CLEATS ON MOTOR FRAME

The cables are clamped to the housing with a pair of stationary cleats as they come out of the motor frame. To prevent chafing of the cables as they drag over the motor housing, a pair of loose cleats are clamped on to the cables at a point which will allow free movement of the cleats on the motor housing. The point at which these cleats are clamped should also be such that the cables themselves will not touch the motor housing at any point. These cleats are made in halves, with the holes for the cables bored through on the line of splitting. This is done so that it is not necessary to thread the cables through the cleats. To give further protection to the knuckle joint connectors against the weather, a box can be employed to house the cables at the point where the leads from the motors are connected to the leads of the car body by means of the knuckle joint connectors. In removing the motor from the truck, it is only necessary to drop the hinged cover of this box and loosen the cleats. A box suitable for this purpose is shown in Fig. 2.

With the arrangement of cables shown in Fig. 1, a natural loop or swing is obtained with a very slight increase in the length of the loop when the trucks are in their extreme position. This scheme will probably take a little longer to install than the usual method of dropping the cables from a condulet on the conduit, housing the cables on the car underframing, and placing the connectors in the swinging loop, but will pay for the extra work in the long run.

ARRANGEMENT OF LEADS

To simplify the changing of motors when failure occurs, it is essential that any motor can be placed on any truck and have its leads in such sequence that connections can be made without crossing the leads between the motor and the car underframing. To do this, the cables at the cleats on the car underframing should be arranged in the same sequence for all motors. Likewise, the cables as they leave the cleats on the motors should always be the same and should line up so that when the motor is placed in the truck, the proper lead at the cleat on a car underframing will be directly over the lead to which it is connected on the motor. In Fig. 3 is shown a suggested arrangement of sequence of leads as they leave the cleats on a car underframing. In Fig. 4 is shown the arrangement of leads as they leave the cleats on the motors. On field control equipment the field tap lead should be brought out at the middle of the cleat. This lead is not shown in the sketch. The sequence of the leads is such that they will line up with the leads as they leave the cleats on the car body. If this scheme of mounting is followed out, it will always be possible to interchange any of the motors by simply dropping the cleats at the car underframing and breaking the knuckle joint connectors. When the new motor is slipped into place, there will never be any question as to how the leads are to be connected, as the leads themselves, as they drop down from the cleats on the car underframing, will lie directly over the leads to which they are to be connected at the cleats on the motor.

H. R. MEYER.

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department

To receive prompt attention a self-addressed, stamped envelope should accompany each query. All data necessary for a complete understanding of the problem should be furnished. A personal reply is mailed to each questioner as soon as the necessary information is available; however, as each queston is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply.

1863—INSULATING PAINTS —Can you advise as to the methods which are used in specifying and testing insulating paints? What are the properties required of an insulating paint? How are tests conducted to insure adherence to these properties?

P.M. (N.Y.)

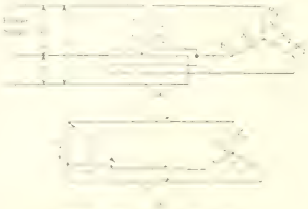
It is assumed that information is desired regarding insulating varnishes rather than paints because varnishes are used extensively for insulating purposes and paints are not. Insulating varnishes are applied to electrical apparatus for the purpose of filling and sealing the other insulating materials so as to exclude moisture and any other foreign matter which would otherwise collect and weaken the insulation. This filling with varnish is also often depended upon to improve the mechanical qualities of the coils and the heat-conducting qualities of the insulation. To be suitable for the above a varnish should have the following properties:—

1—High insulation strength.
2—Elasticity and flexibility.
3—Long life under heat.
4—Moisture resistance.
5—Oil proofness.
6—Smoothness, with a hard finish which will not soften and become sticky under heat.
7—Freedom from corrosive effect on copper.
8—Should bake in a reasonable number of hours.

The tests are usually made by comparing the properties of the varnish under test with those of a known varnish, which may be considered as the standard. Duplicate tests are made on the two (or more) materials and from the records of these tests the varnish best adapted to the application under consideration can be chosen. To test for insulation strength, prepare test specimens on pieces of smooth, highly calendered cambric, 6 inches square by 0.005 inches thick. After drying the cloth, immerse it in the varnish at the consistency at which it is to be used, and draw it out of the varnish at a very slow and uniform rate. After draining, hang it in an oven, which has a temperature of about 212 degrees F. and bake for the time specified by the supplier of the varnish. Apply a second coat in the same manner as the first, except that the top edge of the first dipping should be at the bottom edge of the second. These samples are to be tested between one inch diameter discs, having one-fourth inch radius at edges. Voltage is to be increased gradually until breakdown occurs and the reading taken when failure takes place. About 10 punctures should be made on each piece and the thickness of the specimen should be measured at a number of places. The average breakdown voltage divided by the average thickness in mils will give the average breakdown volts per mil. To test the varnish for flexibility, a glass should be coated with it and the coating given a thorough baking. The film is then tested with the point of a knife. The varnish should come off in a ribbon and not in flakes. To test the varnish for life under heat, samples should be prepared on cambric as indicated above, and placed in an oven at a temperature of 212 degrees F. for a long time test. The samples should be examined every 200, 300, 400 and 500 hours. The specimen showing the best flexibility at the end of these periods has the best heat-resisting qualities. Other specimens dipped and baked twice, as indicated above, should be immersed in water for 24 hours. When taken out of the water, wipe off the excess water and test immediately. The specimens showing the smallest decrease in dielectric strength have the best moisture-resisting qualities. To test for oilproofness, samples applied to cambric should be placed in mineral oil and put in an oven at about 175 degrees F. for 24 hours. There should be no signs of the oil dissolving the varnish film.

L.E.F.

1804—VECTOR DIAGRAM OF SCOTT CONNECTION—With Scott connected transformers, if we supply the power from the three-phase side and put some inductive loads on the secondary ends which are connected in a two-phase, three-wire system as in Fig. (a), kindly give a vector diagram of whole system at the three-phase end and also give general equations of voltage current and power at the three-phase supply end, if possible. This type of load has been actually experienced in the case of an electric furnace in operation. It is not an imaginary problem, but it is my earnest desire to find a solution of this kind of problem.



FIGS 1804(a) AND (b)

G.J. (N.Y.)

The questioner asks for a vector diagram of a three-phase-two-phase transformer supplying an unbalanced load connected in star. It is believed that a mathematical solution will explain the relations better than a vector diagram. In the first place, the general problem for three-phase-two-phase transformation has been covered by C. L. Fortescue in the section on transformers, pp. 405 and 406 in the Standard handbook. The remaining problem consists merely in finding the current that would flow through an unsymmetrical group of impedances with a given supply voltage. This solution will be obtained as follows:

The equations refer to the diagram of connections as shown in Fig. (b) in which the voltages are given as indicated and the impedances Z_1, Z_2 and Z_3, as follows:—

$$Z_1 = R_1 + jX_1$$
$$Z_2 = R_2 + jX_2$$
$$Z_3 = R_3 + jX_3$$

The equations of the circuits based on Kirchhoff's Laws are as follows:—

$$E_a = Z_1I_1 - Z_3I_3$$
$$E_b = Z_2I_2 - Z_1I_1$$
$$I_1 + I_2 + I_3 = 0$$

These equations may be solved by determinants giving:—

$$I_1 = \frac{\begin{vmatrix} E_a & 0 & -Z_3 \\ E_b & Z_2 & 0 \\ 0 & 1 & 1 \end{vmatrix}}{\begin{vmatrix} Z_1 & 0 & -Z_3 \\ -Z_1 & Z_2 & 0 \\ 1 & 1 & 1 \end{vmatrix}} = \frac{Z_2E_a - Z_3E_b}{Z_1Z_2 + Z_1Z_3 + Z_2Z_3 = \Delta}$$

$$I_2 = \frac{\begin{vmatrix} Z_1 & E_a & -Z_3 \\ -Z_1 & E_b & 0 \\ 1 & 0 & 1 \end{vmatrix}}{\begin{vmatrix} Z_1 & 0 & -Z_3 \\ -Z_1 & Z_2 & 0 \\ 1 & 1 & 1 \end{vmatrix}} = \frac{Z_1E_b + Z_3E_b + Z_1E_a}{\Delta}$$

$$I_3 = \frac{\begin{vmatrix} Z_1 & 0 & E_a \\ -Z_1 & Z_2 & E_b \\ 1 & 1 & 0 \end{vmatrix}}{\begin{vmatrix} Z_1 & 0 & -Z_3 \\ -Z_1 & Z_2 & 0 \\ 1 & 1 & 1 \end{vmatrix}} = \frac{-Z_1E_a - Z_2E_a - Z_1E_b}{\Delta}$$

These equations might also be transformed to give the following:—

$$I_1 = \frac{Z_2E_a - Z_3E_b}{\Delta}$$
$$I_2 = \frac{Z_3E_b - Z_1E_c}{\Delta}$$
$$I_3 = \frac{Z_1E_c - Z_2E_a}{\Delta}$$

which is a general solution for a three-phase supply (balanced or unbalanced) supplying power to three impedances (equal or unequal) connected in star. By combining the solution given above and the one given in the Standard Handbook previously referred to, you should be able to obtain the solution in any particular form that you desire.

R.D.E.

1865—Position of Overhead Ground Wire—Fig. (a) shows our practice of attaching the overhead ground wire to the tops of poles. Do you know of any authority who advocates that this ground wire should make an angle with the outside transmission wire of 45 degrees? Could you give me references to discussions, if such exist, on the relative positions of this ground wire? I know there is considerable doubt as to the efficacy of a ground wire, but I do not know of any discussions relative to its position.

[illegible] (PA.)

The efficiency of an overhead ground wire and its location are sources of disagreement between operating men. Apparently the general opinion is that a service test is necessary to determine the suitability of any type of construction. Considerable experimenting has been carried on by the larger transmission companies and the more recent construction of these companies represents what they have found most satisfactory. A resume of recent line construction of various transmission companies gives locations of the ground wire such as to make an angle with the outside transmission wire, ranging from 30 to 60 degrees, the greater number approximating 45 degrees. From a consideration of what is regarded as good practice, and of the electrostatic field around the ground and line wires, it would seem that the location of the ground wire in Fig. (a) is too low to afford maximum protection to the outer transmission wires. An excellent article by Mr. R. P. Jackson on "Potential Stresses as Affected by Overhead Grounded Conductors", in the 1907 *Transactions of the A.I.E.E.* deals with the relative position of the ground wire.

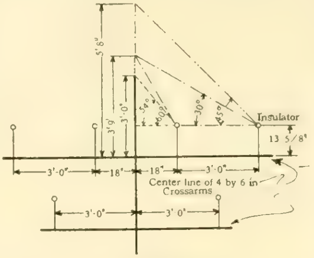


FIG. 1865(a)

The high tension data given in the *Transactions of the A.I.E.E.* for 1914 gives relative positions of the ground wire as developed by field experience.

G.I.G.

1866—Measuring Voltage With One Meter—(a) Please give me a diagram showing the best method of measuring voltage by the use of only one alternating - current direct-reading voltmeter.

1 Supply three phase, three-wire, 3300 volts, 50 cycles.

2 Supply three phase, three-wire, 400 volts, 50 cycles.

3—Supply three phase, four-wire, 230 volts, to neutral.

(b) Also please give the best method of measuring the consumption in amperes and horse-power by the use of only one alternating - current, direct - reading ammeter.

1 Supply 3300 volts, three-phase, 50 cycles, three-wire, connected to a 300 hp motor with slip rings, with short-circuiting device.

2—Supply 400 volts, three-phase, three-wire, 50 cycles, connected to a 75 hp motor, 480 r.p.m., 104 amperes, slip ring machine with short-circuiting device.

3—Supply 400 volts, three-phase, three-wire, 50 cycles, connected to a 15 hp, 950 r.p.m., 18 amp. motor, star and delta connected.

G.L.H. (ILL.)

(a) To measure the voltage between various phases of a three-phase circuit, either three-phase, three-wire or three-phase, four-wire with one voltmeter, it is necessary to use a voltmeter receptacle and voltmeter plug or some type of voltmeter switch either of the drum or dial type. On circuits of 550 volts or less, it is customary to connect the voltmeter directly across any of the phases by the use of voltmeter receptacles. When the voltage on an alternating-current circuit is above 550 volts, potential transformers are used, reducing the voltage to about 100 volts for metering purposes. Figs. (a) and (b) show the method of connecting a voltmeter to a 3300 volt, three-phase circuit. Fig. (a) shows the use of a voltmeter switch to transfer the voltmeter to the various phases while Fig. (b) accomplishes the same result by using an eight point voltmeter receptacle and a four point voltmeter plug. The voltmeter switch shown in Fig. (a) is shown in the *off* position. By moving the switch to position *a* the voltage between leads *1* and *2* will be indicated on the voltmeter; moving the switch to position *b* will give the voltage between leads *1* and *3* and to position *c* will give voltage between leads *2* and *3*. The eight point receptacle method shown by Fig. (b) will indicate voltage between leads *1* and *2* when the plug is inserted in the four receptacles at the right, between leads *1* and *3* when the plug is inserted in the middle receptacles and between leads *2* and *3* when inserted in the left hand four receptacles. Fig. (d) shows connections for reading the voltage on a 400 volt, three-phase, three-wire system. In this case the potential transformers are omitted. To read the voltage between any phase and neutral on a 230 volt, three-phase, four-wire system, three four-point voltmeter receptacles are used, as shown by Fig. (c). (b) For connecting the ammeter in the various lines, small drum type switches are much used. These switches are designed so that the circuit is not opened when passing from one position to the

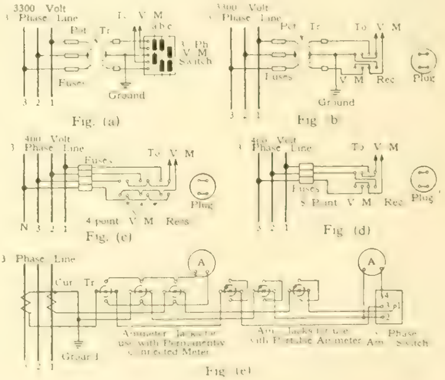


Fig. (a) Fig. (b) Fig. (c) Fig. (d) Fig. (e)

FIGS. 1866(a) to (e)

other. Receptacles or jacks are also used at colleges and places where much testing is done. One type cuts into the circuit an ammeter which is permanently wired to the receptacles. Another type has the leads from a portable ammeter connected to the plug, and thus cuts into the circuit when the plug is inserted. Current transformers are usually necessary when the current to be measured exceeds 20 amperes. On three-phase, three-wire lines, two transformers are sufficient. Fig. (e) shows connections using current transformers and either of the switching schemes mentioned. For measuring the horse-power of an induction motor, a poly-phase wattmeter or two single-phase wattmeters is the desirable equipment. A scale reading directly in horse-power may easily be constructed by remembering that one horse-power equals 746 watts. An ammeter cannot be used to indicate the horse-power of induction motors with any degree of accuracy on account of the variable power-factor characteristics of different motors and on account of variations in the supply voltage. An ammeter is, however, sometimes used as an approximate indicator of the load, and might be calibrated as such for use on one particular motor on a constant supply voltage. The calibration would be performed by inserting the ammeter and a poly-phase (or two single-phase) wattmeters in the primary circuit of the motor, using potential and current transformers where required. R.M.R.

1867—Temperature Indicator for Fuse—What would you think of an indicator to show the temperature of a fuse in use, made to indicate the percent of maximum temperature, using a standard renewable fuse of larger size to contain the fuse, one end cap to have a metal tube closed at the bottom with a shoulder on the inside of the fuse and a nut outside to clamp the tube to the end cap, the tube end being open at the top. A thermometer to be inserted in the tube after the fuse is assembled. Would the metal tube or the heat of the arc crack the thermometer? The thermometer would be of the clinical or maximum self registery type to indicate maximum demand, at the time the fuse blew. Also a standard thermometer could be calibrated for amperes probably. J.E.M. (Mich.)

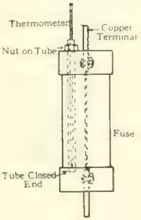


Fig. 1867(a)

It would be dangerous to have any conductor inside the fuse casing other than the fuse element. The metal tube mentioned would very likely cause a reestablishment of the circuit in case of an overload, and damage to the fuse and anybody who happened to stand close by, in case of a short-circuit. It would be possible under steady loads to get a very rough approximation of the current in amperes or percent of the maximum temperature in this way, when the fuse is operating under normal conditions, but the hazard mentioned above, and the variables make the device impractical. M.J.S.

1868—Grounding Instrument Transformers—For parallel operation of generators, do you think it is necessary to ground the secondaries of current and potential transformers used for voltage regulator service and for line drop compensation? If it is necessary to ground them or not will you please advise why. Because the reactance between the points regulated exceeds eight percent, and each machine has its individual voltage regulator, we use one current coil for each as shown in Fig. (a) instead of two cross connected and one potential coil for each regulator. G.D. (Ill.)

The instruments should be grounded for the same reasons that apply to the grounding of all instrument transformers; namely, that there is less danger to human life, and that furthermore a fault in a transformer is more readily detected. The connections shown in Fig. (a) are correct for generators which have separate voltage regulators.

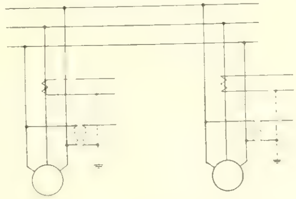


Fig. 1868

It is the connection always used for such cases and no induction compensator is required, because the voltage and current are already 90 degrees out. The reactance value of eight percent between regulator locations is sufficient to prevent excessive cross currents, even if no compensating arrangement were in use. L.A.T.

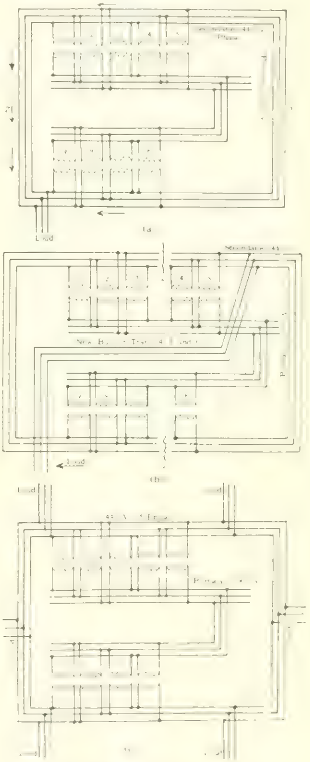
1869 — Transformer Connections — Please discuss the comparative advantages of the connections shown in Figs. (a), (b) and (c). As an example take nine transformers arranged as per Fig. (a). All the load leaves the bus at *X* and we have five transformers on one side and four on the other, with a secondary bus making a complete circuit around the transformers. Will not most of the current flow from the transformers in the direction of the arrows and very little at *Y*? Do you think this a good arrangement? Would it not be a better plan to cut the secondaries at Z and make three separate banks such as *1*, *2* and *3*; *4*, *5* and *6*; and *7*, *8* and *9*, and to install a new secondary bus from transformers *4*, *5* and *6* as per Fig. (b)? Would Fig. (c) be O.K. if the load was taken from the bus as marked on the diagram? J.G.W. (Calif.)

In general, a ring bus as indicated by Fig. (a) operates satisfactorily. The loads carried by different parts of the bus are not necessarily the same. For any bus arrangement the division of current can be determined—for instance, the middle bus in Fig. (a) has four transformers connected in the upper group and two in the lower.

Let a= length of bus from upper group to *X* by way of *Z*.

b=length of bus from lower group to *X*; and

c=length of bus from upper group to lower group by way of *Y*.



Figs. 1869 (a),(b) and (c)

Then the loads for the various sections, expressed in terms of a transformer load, are as follows:—

Through section $Z = \frac{6b + 4c}{a + b + c}$

Through section $Y = \frac{2a + 4b}{a + b + c}$

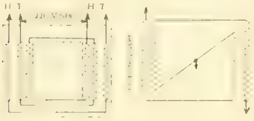
Through the section between the lower group of transformer and $X=$

$$\frac{6a + 2c}{a + b + c}$$

The bus arrangement indicated by Fig. (b) will have equal currents in all sections of the bus, but the extra copper required for the additional auxiliary bus could probably be more economically used in reinforcing the part of the bus in Fig. (a) that carries the greater current. The arrangement shown in Fig. (c) should operate satisfactorily. J.F.P.

1870—Poor Regulation of S[illegible] Connected Transformer—We have two 7200 volt primary to 220 volt secondary transformers, core type, wound as Fig. (a). These were required to be put on three-phase, 7200 volt, primary circuit, two-phase, 220 volt secondary. The high-voltage side of each transformer has 1960 turns, and low voltage 60 turns, 980 and 30 turns respectively on each leg. It was therefore necessary to put an 86.6 percent tap on the high-voltage side on one transformer and middle taps on the high-voltage side of the other for Scott connection. This was done by taking off 260 turns on one leg of the primary of one transformer and bringing out the end for a lead, and bringing out a tap between the legs of the other transformer thus making it possible to Scott connect them. It was found that the voltage balanced perfectly on the secondary without load. When a motor load was applied, the main transformer took 320 amperes at 220 volts and the teaser 130 amperes at 200 volts. Kindly advise why these transformers do not balance better when loaded and how a correction for the unbalancing can be made.

G.P.E. (N.Y.)



(a) (b)

FIGS. 1870(a) AND (b)

The unbalancing under load is due to the fact that the high-voltage windings on the two legs are not interlaced. The current in the teaser must flow through the two halves of the main transformer. Since there are no equivalent ampere turns on the secondary side of the main transformer, the impedance of the teaser is increased by an amount corresponding to the impedance the main transformer offers to the teaser current. If the two halves of the winding of the main transformer are interlaced, this impedance is greatly reduced and the unbalancing under load correspondingly reduced. If the high-voltage coils on each leg are wound in two layers, it is possible to reconnect the windings and interlace them as shown in Fig. (b), provided the insulation between layers is able to stand the increased stress.

H.F.

1871—GROUNDING HIGH TENSION LINES—In the system shown in Fig. (a) it is desired to select the most advantageous grounding combination. Points *a*, *b* and *c*, are available for grounding. Please discuss the operation of the system with all three points grounded at the same time, with *b* and *c* grounded and with point *a* only grounded. Would not this last ground (i. e., at *a* only) give an entirely stable system and also cause the feeder circuit breakers to open on the occurrence of a ground on a phase wire?

M.J.I. (D.C.)

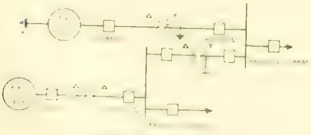


FIG. 1871(a)

Grounding the circuits at *b* or *c* will cause the feeder circuit breakers to open in case one line grounds on the 88 000 volt feeder, but a single ground on the 44 000 volt feeder will not cause any circuit breakers to open. There is very little gained in protection by grounding at both *b* and *c* over grounding at one place only. The grounding at *a* has no effect whatever on the operation of the 88 000 or 44 000 volt circuits, on account of the insulated transformer between the 11 000 volt circuits and the remainder of the system.

J.F.P.

1872—RATIO OF CURRENT TRANSFORMERS—I have a current transformer with hinged laminations, a hole in the center for the primary, and the secondary coils about as shown in Fig. (a)—ratio 250 to 5. The secondary covers only a small portion of the core. Can these transformers be used with as many primary turns as possible to pass through the hole. Will the ratio of transformation be changed in proportion to the ratio of the number of turns.

J.E.MCH. (MICH.)

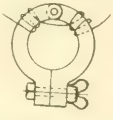


FIG. 1872 (a)

To circulate five amperes through a given secondary load, a definite number of ampere-turns is necessary in the primary. If the turns are increased, therefore, the primary amperes are decreased in the same ratio. As many primary turns may be used as the space in the opening permits.

J.B.G.

1873—OVERLOAD PROTECTION—In order to protect our power transformers from overload, we are planning to use a five ampere, hand reset, demand meter working on the thermocouple principle, which in case of overload puts in contact a bell alarm circuit. Connections are as in Fig. (a). But our current instrument transformer circuit passes through overload relays, which in case of overload put in contact a bell alarm, and also trip the oil circuit breaker. Is it necessary to use such a demand instrument when we already have overload protective devices?

G.D. (ILL.)

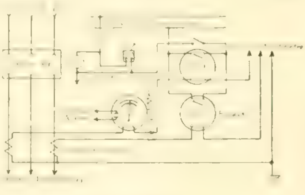


FIG. 1873(a)

It is customary in modern relay practice to set all relays for short-circuit instead of overload current values. This applies particularly to systems in which the selective idea of protection is carried out, since it is necessary to allow certain time intervals between successive circuit breakers, and in order to do this the relays must be set for short-circuit values. Where this custom is followed, it will be necessary to use some kind of auxiliary device, such as a contact making demand meter, for indicating overloads. While the bulk of the relays on most systems are set with the idea of securing selectivity of action, there may be cases where it is desired to protect apparatus against overloads, as well as against damage from short-circuits. In such cases, the relays are usually set to operate for any value above a given load, and it is not necessary to use any auxiliary indicating device, since the relays will perform this function. It follows therefore, that the necessity of the contact making demand meter depends upon whether or not the relays are set for overload or short-circuit values.

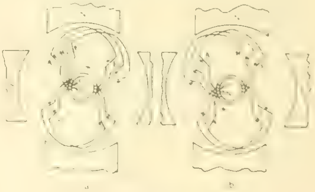
E.A.H.

1874—DIRECTION OF ROTATION—In a wave winding on a four-pole, direct-current armature, is the direction of rotation changed by changing the connections from progressive to retrogressive?

A.H.B. (D.C.)

The direction of rotation of the motor will be changed by changing the connections of the armature winding from progressive to retrogressive. This can best be shown by diagrams representing parts of armature windings which are connected in the two different ways. Fig. (a) represents a progressive winding, while Fig. (b) represents a retrogressive winding. A series, or wave wound, armature winding has two circuits from the positive brushes to the negative brushes. If one of these circuits of a progressive connected armature be traced out, beginning at bar *O*, it will be found to pass through two coils and to come to bar *P*, the next bar ahead of *O*. If the complete winding were traced out it would be seen that connections progress around the commutator as indicated by the arrow, until the winding closes at bar *O*. If bar *O* is under a positive brush of the motor the coil sides between *A* and *B*, which are under a north field pole, will carry current away from the commutator, while the coil sides between *B* and *C* will carry current toward the commutator. This relation between armature current and field poles will cause the armature to rotate counterclockwise. Fig. (b) shows how a retrogressive winding differs from a progressive. Coil side *D* connects to bar *N*, instead of bar *P*, and the connections proceed around the commutator as indicated by the arrow. If bar *O* is under a positive brush the current in conductors between *A* and *B* under the north pole will be in the direction toward the commutator, and the armature will rotate clockwise.

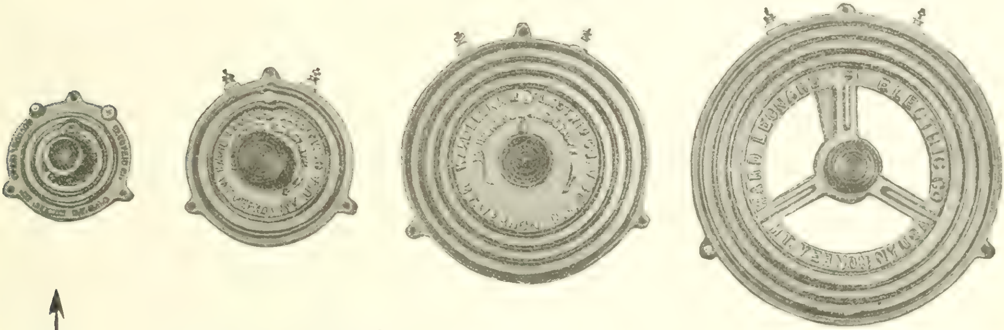
C.H.W.



FIGS. 1874 (a) and (b)

Ward Leonard

Motor Field Rheostats



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Electrical Material Co. San Francisco
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NATIONAL SAFETY SECTION

FIRE EXTINGUISHMENT

Continued

SAWDUST AND SODA

A mixture of sawdust and bicarbonate of soda (about 10 pounds of soda to a bushel of sawdust) is a valuable extinguishing agent in fires of inflammable liquids. This mixture floats on the surface of the burning liquid, shutting off the oxygen supply and smothering the fire. It is much more effective than sand in putting out fires of inflammable liquids. Unless foam extinguishers are provided, a supply of sawdust and soda should be kept on hand at all containers of varnishes, lacquers, oils, paints and similar liquids. The principal point in its favor is its low cost.

SUGGESTIONS

The efficiency of fire-fighting apparatus depends largely upon its proper use. Unless the hose stream, the extinguishing fluid, sand or sawdust is directed on the base of the fire, its value is lost. Employees should be instructed in the proper use of all equipment, and given an occasional opportunity of seeing it in actual operation. Fire extinguishers and fire hose racks are sometimes found inaccessible on account of material stacked in front of them. It is also a fact that the employees in many plants do not know where the fire apparatus is located. To be of value such apparatus must be put into use immediately after fire is discovered. It should, therefore, be placed prominetly and kept easily accessible—if not, it might as well not be provided at all. Some plants place extinguishers along center aisles with a red mark on floor or around column or post on which extinguisher is hung, and often with a red light over it at night.

Inspection should be made of all fire-fighting apparatus including extinguishers, fire barrels and pails, hose, hydrants and valves, at least once each week. Many of the large companies require such an inspection every day. A competent man should be assigned to this inspection service and should periodically make a complete and detailed inspection of all apparatus and equipment, keeping a record of the inspection on a blank for that purpose. Purposes of inspection are to determine (a) what possibilities of fire outbreak can be eliminated, (b) whether fire-fighting equipment and apparatus is in good condition and accessible.

It has often been the case that extinguishers were found empty when most needed. In order to know at a glance whether an extinguisher has been tampered with, through mischief or maliciously, some companies use a car seal to fasten handle of extinguisher to hanger bracket. These seals are easily broken, and therefore do not interfere with use of the extinguisher. They are, however, not replaceable, and hence enable the inspector to know whether extinguishers have been disturbed for any reason.

BELTS AND BELT GUARDS

Belts must be reckoned among the industrial appliances which have occasioned a great number of serious accidents. Attention cannot be too forcibly called to precautions which should be taken in the management and safeguarding of these dangerous appliances. Leather belts are in general use, except in situations where there is an excess of moisture, heat, grit or other exceptional conditions.

STRENGTH.

Engineering manuals indicate a strength of 2 000 to 5 000 pounds per square inch for solid leather belts. This may be reduced at lacing or joint, even if well put together, to about 1000 to 1500 pounds. The ordinary type of belting cannot safely stand a temperature higher than 130 degrees F.

WORKING LOADS.

The safe working load may be learned from manufacturer of belt and this load should never be exceeded.

TENSION.

Belts should be adjusted to tension under condition as closely approaching normal as may be devised. In damp or rainy weather, belts are liable to stretch. This fact should be considered in computing tensions in new adjustments. Countershafts with adjustable hangers are advisable for new installations.

LENGTH.

The average distance between shaft pulleys for small belts should not exceed 15 feet; for larger belts, 25 feet and for main belts on large pulleys, 30 feet.

SPLICING AND LACING

A general rule in many large plants reads about as follows: "Endless belts should be used wherever possible; in case endless belts cannot be used (and the circumstances permit), then the belts should be laced with rawhide or leather lacing. Belt hooks or metal lacing should not be used except where absolutely necessary in emergencies." The objection to the use of metal in joining belts is its probability of presenting sharp projections which will injure hands or catch clothing. For this reason if such lacing is used at all, special care should be taken to see that it is not used in a situation where the hand or clothing is likely to come into contact with the belt.

CEMENTING AND SPLICING

All authorities agree that splicing and cementing is safer than any other method of joining belts. Claim is also made that belts joined in this manner will wear longer, cut labor cost, do smoother work and give better service. Ends of belts should be carefully scarfed down, covered with cement, and firmly pressed together. It is essential that the work be carefully done by experienced workmen. The scarfing should be so arranged that the pulley where slipping is more likely to occur (i.e., the smaller pulley) will tend to smooth down the scarf end against which it rubs in the event of a slip, instead of tending to roll this end up. Vulcanizing, with stepping splice, is recommended for rubber belts.

LACING

When the belts are laced, rawhide or leather lacing is recommended. Ends should be cut short down to the belt and care should be exercised to avoid broken turns. Belts usually weaken and break near the lacing. To avoid weakening belt too much, holes for lacing should be made with oval punch, with the longer diameter parallel to sides of belt. If the width of the belt will permit, edges of holes should not be nearer than ½ inch from sides nor less than 1 inch from ends. The second row of holes should be staggered and about same distance from first row as first row is from end of belt to be spliced. Start lacing from the center, lacing both sides with equal tightness. Do not cross lacing on side running next to face of pulley. Keep ends of belt exactly in line while splicing. The beltman should be protected against the accidental starting of the machinery, preferably by locking the controlling device. When the line shaft cannot be stopped, special precautions should be taken to prevent the belt coming into contact with the pulley or wrapping on the shaft, by the use of a belt perch or other attachment.

WIRE LACING

The use of rawhide or leather lacing is advocated in preference to metal lacing. The danger from wire lacing arises from two principal sources: The working out of the clinched ends of the wire and the ragged ends produced by a fracture. If the wire lacing must be used, it should be in some form of spiral continuous wire stitch, so that there will be only two clinching points to turn into the leather on each end of the belt, the two lacings being hinged together. Wire lacings, unless machine made, require a high degree of skill. Care should be taken that the wires lie below or flush with belt surface and do not touch on the pulley. Single wire lacings, without hinge, should be used—if at all—only over large pulleys. Lacings made of separate wire staples, pressed in, with or without the use of a hinge, are particularly objectionable, because the wearing of the belt on the pulleys tends to throw the clinched ends out. Their extreme sharpness constitutes particular danger.

TOOTHED CLINCHES

Heavy toothed clinches of the so-called "alligator" type are less dangerous than the wire lace or wire staple type, partly because of their strength and partly because the clinched ends run on the pulley side. The best types have a double grip.

THE ELECTRIC JOURNAL

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The National Electric Light Association Convention at Pasadena

R. H. BALLARD
President,
National Electric Light Association

SINCE electricity first began to take its part in the world's work, there has never been a time when the demands for its generation and distribution have been so enormous as the present. Innumerable problems of national and international magnitude will present themselves for solution at the National convention of the National Electric Light Association, in Pasadena, California from May 18th to May 22nd.

Within the past eleven months, I have on several tours come into the closest personal contact with the men in every section of the United States who are earnestly endeavoring to make electricity fulfill the work which nature and destiny have thrust upon it. Their problems are multiform, difficult and intricate, and the forth-coming convention at Pasadena impresses me as a forum in which many of the best thinkers of the country will forge their ideas into tools of wonderful efficiency, for the welfare of the people of the present and the future.

R. H. BALLARD
Vice President,
Southern California Edison Company

The East, the North and the Middle West, with their enormous populations demanding the service which only electric energy can supply, are being called upon to take initiative action which will have its bearing on domestic life and every branch of commerce and industry. Warfare which involved the world, brought us to a realization of the potentiality of electricity for light, heat and power some ten years earlier than we would have comprehended it under the normal conditions of peace. Scarcely had the armies of Germany begun their sweep across the Belgian frontier, than it was apparent to the astute that such resources of the earth as coal, oil and lumber, were subjected to attack, and that, unless carefully conserved, their excessive use would mean their premature depletion.

Grouping of the territory covered by the National Electric Light Association into geographical sections, will facilitate greatly the systematic discussion of subjects which cannot properly be divorced from local conditions. The Passadena convention will, therefore, be more in the nature of a national clearing house of electrical problems than any previous gathering.

Financing the new electric era, and so adjusting the increased use of electric power that it will not tend to the destruction of capital honestly invested in other processes for the production of energy, and at the same time giving electricity full opportunity to perform the tasks that it is fitted to do, is of vital interest to the bankers of America, and the Pasadena convention is of necessity their timely occasion for acquiring direct and first-hand knowledge.

Power generating companies are being called upon, from the Atlantic to the Pacific, to increase production, as the prices of coal, oil and other portable fuels advance. The railway lines which cobweb the continent and perform the gigantic work of transportation are probably the greatest consumers of oil and coal. It is apparent that the electrical industry is face to face with the electrification of some of the steam railroads, and with the necessary increases of their generating capacity to carry this new and heavy load. Upon the manufacturers devolves the necessity of turning out electrical machinery and appliances, which will facilitate steam and hydraulic generation and conserve the amount of current required for the operation of railroads, factories, lighting and domestic purposes.

To make every home in America an electric home, and to see that the appliances for doing the work that has been done by coal and oil are of the highest type, and perfectly installed, will be important matters for jobbers, dealers, and contractors, but all of these themes must be in tune with this one great chord—service. Service with profit; service that will make electricity serve the people as no other servant has served it; service first, last and always—the service that really serves.

Effect of Electrical Removal of Limitations

Gen. Guy E. Tripp
Chairman,
Westinghouse Electric & Mfg. Company

PERHAPS the most fundamental change in our industrial practice that has occurred within the present generation is the substitution of mechanical for animal power. Not only has the automobile replaced the horse, and the street car motor the mule, but the farmer's grain is threshed and his cows are milked by mechanical power, while no household is complete without the vacuum cleaner and electric washing machine, and even the palm leaf fan has been supplanted. It would be difficult to estimate the effect of this substitution on our daily life and on the progress of the nation, but it is interesting to note that it has not been brought about by any basic discoveries in the source of power. Power is still produced by burning fuel under boilers or by utilizing the energy of falling water, and in much the same way as it used to be produced except that improved design and construction has lowered the cost. The development which has made this fundamental change possible is the generation and distribution of electricity which, although not a primary source of power itself, is now the most convenient, in fact, the only available agent for the distribution and utilization of power over wide areas and in units as large or as small as the needs of the consumer may require.

As the art progressed and it became commercially feasible to distribute power over larger and larger areas from a single source, improvement in steam and water power generation was stimulated and the size and efficiency of generating units steadily increased. We are familiar with the rise and fall of the isolated plant which, though playing a very valuable part in its time, had to go the way of the horse and the wash tub when the march of improvement made it possible for the central station to supply power with greater reliability and for less money. Industrial progress is inexorably controlled by economic laws, so that the wonderful development of today may be found in the scrap heap of tomorrow, should something better be found.

Indications are not lacking that the next progressive step will be the creation of the "Central Station of Central Stations" or, as it has come to be called in some quarters, "The Superpower System". The same reasons which resulted in discarding the isolated plant now point towards elimination of the small central station and perhaps many of the large central stations as well, which for one or another reason may not be able to produce electric power at as low a cost as it can be supplied by a superpower system. This advance in the art involves no new principles, neither is it entirely for the future, since substantial progress has already been made in a number of districts. In California and in the southeastern states, owing to favorable local conditions and the enterprise of far-seeing men, there already exist interconnected power lines serving large areas. It is, however, in the densely settled manufacturing districts of the North Atlantic seaboard that perhaps the greater economies are possible, although so far there has been less progress in this region than elsewhere. Having had the economic possibilities brought to their attention, the Federal authorities are now considering a Government power survey of the North Atlantic seaboard from Boston to Washington which, if undertaken, should show both the power demand and the power resources of that region. A preliminary and confessedly approximate analysis indicates that the savings to be effected by developing and pooling the power resources and by their most economical use will be of the order of magnitude of hundreds of millions of dollars per year. Large as these figures sound they by no means correctly measure the benefits to be secured by such a plan, because the maximum advantage afforded by electrical distribution is not in the reduction in the cost of doing things in the old way but the opportunity afforded to do old things in a better way, and to do many new things which were not before possible.

The electrification of a steam railroad, for example, effects a saving in fuel which reliable tests have shown may conservatively be stated at fifty percent. Electrification also permits many other striking economies, but the real and controlling advantage is not economy, but the increased capacity of the railroad to transport additional freight and passengers without the necessity for the construction of expensive additional tracks or terminal facilities.

Our entire railroad transportation system has been built up around the characteristics of the steam locomotive and is subject to its limitations. Electrification removes many of these limitations and permits a reconstruction of traffic methods so radical as not always to be easy of comprehension. The steam locomotive is a complete independent unit. It carries its boiler and its power is limited by the steam which that boiler can generate. Furthermore, its tractive effort is limited by the weight on its drivers. The electric locomotive on the contrary has available the steam power of all the boilers in its power house, while the ability to operate any number of locomotives as a unit from one cab also removes the traction limitation. In effect, electrification substitutes for a rigidly limited motive power one that is practically unlimited. The result is that the maxima of train tonnage and speed are no longer set by motive power but are controlled perhaps by drawbar strength, length of sidings, a proper regard for operating safety or some other features established by existing conditions, but which are not fundamental and, therefore, are susceptible of modification when necessary.

As the country's traffic demands have grown, nearly every transportation system has developed one or more congested sections which limit its capacity. Therefore, the far-reaching effect of removing these limits or of their very considerable expansion can well be left to the imagination.

What may be accomplished by electrifying certain sections of our steam railroads is paralleled by the possibilities of accomplishment in many other industries. I have referred to it briefly above to illustrate and to emphasize some of the industrial possibilities which the advance in the electrical arts has given our country.

It may be safely predicted that, in their efforts to rehabilitate their industries and under the tremendous burdens imposed by the world war, the nations of Europe will in time compete for foreign trade more keenly than ever before, even if they do not vigorously invade our domestic markets. Among its other advantages, the United States possesses power resources, both in fuel and in water, exceeding those of any European nation. But it will only be by the exercise of keen foresight, coupled with initiative and courage, and fostered by liberal and just laws that we can expect to reap the benefit of this advantage.

The Greatest Development in Electrical History

MILAN R. BUMP
Chief Engineer,
Henry L. Doherty & Co.

A FEW YEARS ago at a meeting of the Ohio Electric Light Association, in discussing the rapid changes which were taking place in the electric light and power industry, the writer made the prediction that the old-time standards by which commercial development had been judged were rapidly becoming obsolete. Up to that time an electric central station company having gross earnings of six or seven dollars per capita was considered to be progressive in the development of its territory. Within the past four years, conditions have changed so rapidly that there are cities today where the central station receipts are already in excess of thirty dollars per capita; and in the same cities the power shortage seems to be more acute than ever before. This applies particularly to the industrial districts of Western Pennsylvania and Eastern Ohio. During the war the shortage of power in this district was particularly acute and was the subject of serious consideration.

A recent survey, bringing down to date the reports of Government engineers made in 1916 and 1917, indicates that the shortage at this time is much more acute than it was at any time during the war and that there is an urgent need for the addition of not less than 500 000 kilowatts of capacity in this territory before the end of 1921, in addition to the large capacity now under construction, and without taking into account the needs of the steam railroads.

This industrial growth has come about with extreme rapidity. As an example, one town of thirty thousand people in Eastern Ohio reported a peak load of 1 500 kilowatts and a yearly generation of six million kilowatt hours for the year 1914. This same town now has a peak load of 24 000 kilowatts and the yearly generation will exceed 80 million kilowatt-hours, while the load now in sight will more than double the present output.

This rapid development, together with the change in the economies effected, has caused power plants to be built and extended rapidly. All of the old rules regarding depreciation, covering obsolesence and inadequacy, have failed and as a result large investments are now practically useless because they are outgrown, even before the appearance of newness has passed.

The change in central stations from electric light as the primary production to the primary production of electric power has revolutionized the practice of rate making. It is only a few years ago that the central station operator was guided by the idea that he was disposing of the by-product of off-peak capacity and depended primarily upon electric lighting to carry his base charges. Furthermore, it was frequently necessary, in order to compete with the then existing private plants, to sell power at figures closely approaching the cost of power at the switchboard. Now the problem is entirely reversed and prospective power users realize that, in rate making, the full value of the plant capacity required for his uses must be taken into account.

The war served to accentuate this situation, which was rapidly becoming serious in many localities, due to the use of power rates installed on the off-peak theory. During the past three years, it has been necessary for practically every power company in the country to make rate adjustments and the educational value of the work of adjusting these rates has had a decided effect upon the industry. There has been a marked change in the attitude of state and municipal regulatory bodies and further changes are taking place. Power companies today have practically no difficulty in securing recognition in their rates for their increased operating costs.

There also is another factor, namely, the increased cost of capital, which is gradually being brought to the attention of regulatory bodies and which must be fully recognized, if a very serious situation is to be averted. There seems to be practically no limit to the amount of power that can be utilized in this country, if plant capacity can be made available. It is not merely a question of the financing of public utilities, but an enormous industrial activity must be financed and the industries desiring to use power are as vitally interested in the working out of a financial plan as are the central stations. Money cannot be obtained today at the rates which formerly prevailed. It is obvious, therefore, that one of two things must happen, if the power plant developments are to continue. Either the Public Service Commissions must recognize the present-day costs of money and, in authorizing rates for service, take into consideration the rapid amortization of the investment made necessary under present conditions, or the industries affected must assist in financing the plant extensions and must carry the securities of the power companies, until a market does exist for the disposal of these securities to investors.

General recognition of the desirability of purchasing power seems to prevail throughout the country. The economic theory of the central station is now recognized as being sound and today almost every power user prefers to purchase power rather than to build his own private power plant. The quantities of energy are reaching such magnitude that the economy of power plants located close to fuel supply and to adequate condensing facilities is apparent. The trend of this development will be to relieve the railroads of the burden of handling tremendous quantities of fuel and to assist them in meeting the present problems of congestion.

A statement recently made to the effect that the railroads themselves might cut their own fuel requirements to the extent of more than 100 million tons per year by eliminating steam locomotives through electrification, adds further proof of the recognition of the value of large central stations. In many localities, groups of central stations could be better served with one or two very large stations located nearer the source of fuel supply. The only thing holding back the development of these projects today is the financial situation. If the financing can be arranged, it appears that there will be a growth of power plant capacity, during the next five years, that will mark the period as the one of greatest development in the history of the electrical industry. The theory is sound and every economic reason calls for the development. It does not seem over-optimistic to say that a way must be found and will be found to carry out this development.

Sound Central Station Policies

JOSEPH B. McCALL
President,
Philadelphia Electric Company
Past President National Electric Light Association

IT IS UNNECESSARY to dwell here on the nature, importance and value of co-ordination, co-operation and service. They are elemental factors upon which productive industry is based, and their derangement causes such conditions as are now generally prevailing. Today the people of the country are too full of talk about individual rights, and pay too little attention to the performance of their individual duties. "The laborer is worthy of his hire", as the Good Book says, but he ought to deliver the goods. There is no real conflict between individual rights and duties. They are interdependent and could not exist separately without a reversion to savagery. The artificial conflict stirred up will be vanquished by truth and fair dealing. It is up to the men in the operating departments of their particular business to have the proper attitude towards those under their authority. Set an example of industry; treat the men fairly; consider their needs and circumstances and you will find you can steer them away from dangerous currents of discontent. Fortunately, most of the employees in our industry think for themselves and are less likely to be led by deliberate or deluded disciples of unrest. Central Station men have given and will give full effort to their work. To condense the foregoing—Join up individual rights with individual duties.

The fuel problem is one to which everyone in the electrical industry should be giving attention. The high pile has become the low pile and the low price the high price, and the latter is gradually becoming prohibitive, especially under rate regulation, because relief cannot come fast enough. While this is a vital problem with us, the coal question is of national importance as well. Coal is a national asset. From the 75 percent of the nation's coal that is burned under boilers to produce steam there is obtained less than 13 percent of its latent energy for useful purposes. The electric central station is a positive factor for betterment in this situation as the power company obtains two to three times the efficiency from coal that small isolated plants can obtain under the most favorable circumstances.

It has been estimated that the public utilities of this country consume 50 000 000 tons of coal per year. This tonnage, at an average price of $6.00 per ton delivered, represents a coal bill of $300 000 000. In Philadelphia, our estimated requirements for this year are 1 000 000 tons of coal. If we could obtain an increased efficiency of one percent in generating energy, we would save, on this basis, 10 000 tons of coal during the year which, at the above mentioned cost, would represent a saving of $60 000. Such an increased efficiency of one percent represents a saving equal to the interest on an investment of $1 000 000. It means that much greater ability to finance extensions. This principle can be applied to total station costs—the fundamental place for economy. We should especially bend our energies in this direction. It promises the most fruitful field for individual and organized research and investigation.

The National Committee on Gas and Electric Service is now considering a union of interests looking towards lower prices for coal, based upon total demands, and also, transportation costs by different methods of delivery, especially applied to the summer season, equalizing the use of labor and rolling stock on the transportation systems. This in turn should effect a broadening of the working operations at the mines. The importance of this work cannot be over-estimated. It means continued economies to the ultimate consumers with fair return to the employes and investors of the utility company.

More attention is being paid today than ever before to the purchase and sale of power between companies in the same or adjoining territories. This is an economically sound policy that should be developed. It will benefit, mutually, the public and utility companies and assist greatly in extending the advantages of central station service. Economy of investment will obviously result from thus using each others reserves; permitting a helpful saving of investment by the reduction of the necessary reserve apparatus. It will lead to such economies as will insure a profitable business future. Financing will be easier by thus conserving money for investment. Less investment will lie unproductive and therefore earnings will be increased. This will enable us to protect rates to the public and increase the dividends of our stockholders. This subject is of such importance that it deserves the closest study by all of us engaged in this business. There is at present much available data, and it should be gathered and made easily obtainable.

Contemplated changes in the National Electric Light Association organization and constitution will be considered at the Convention in Pasadena, and it is believed that changes will be made which will result in the Geographical Sections, such as the Pennsylvania Electric Association, becoming increasingly more important. The new plan will permit more intensive work and avoid much duplication. This emphasis on the Geographical Section is the logical development.

Reliability is still the cardinal principle of the central station industry. During the war years, most electric companies were strained to the maximum to supply essential industries; on the other hand, needed materials and finances for maintenance and extensions were not available. As a result we must now redouble our efforts to bring our plant equipment up to such standards as will insure reliability and continuity of service.

The Water Power Situation

Franklin T. Griffith
President,
Portland Electric Light and Power Co.

In order to do their full share in the upbuilding of the communities in which they are located, public utility companies must add to their equipment, and extend their service lines with sufficient rapidity to keep pace with the growth of the industrial load. Often this industrial growth is at a greater rate than that of the increase in population. A very important part, therefore, in the community life is played by the utility company and its responsibilities are heavy.

One of the principal difficulties confronting many companies is that the community as a whole does not clearly understand that, in order to secure the funds necessary to make the desired additions to plant and equipment, it is necessary that the money already invested be allowed a fair return. This is only possible when the utility commissions allow the utilities such rates for service as will produce the fair return. There is much room for improved co-operation between the utilities, the commissions and the public, to the end that the community may forge ahead at the maximum rate.

During the war, interconnections were made for the purpose of transferring electric energy from certain systems having surplus capacity to adjacent systems lacking capacity. The benefits derived from these interconnections were so marked that there is now a general movement on, which will result within a few years, in a more or less complete tying together of the systems of the country.

Much progress has already been made along these lines in the West where the benefits to be derived are very large. In this part of the United States, electric energy is produced principally by the use of water power, and the creation of large transmission networks afford the opportunity of shifting energy from one system to another and the conserving of flood waters, which otherwise would go to waste, for use during the season of short water.

Inasmuch as approximately 70 percent of the potential water horse-power of the United States is located in the Western states, all but a few percent of which is subject to federal control, on account of being all or in part within the confines of federal reserves, and because the high costs of Western fuels make water power the principal source for the production of electric energy, it is apparent that a more complete utilization of the water power is the controlling factor in the development of industry in this region.

The result of the interconnection of systems will be, in effect, a monopoly. It will be, however, a monopoly for the benefit of the public, as much as for the utilities, and it will be a signal step in the West toward the conservation of natural resources, for it will make possible, by the use of water which otherwise would be wasted, the saving for future use of large quantities of fuel oil.

The public will be amply protected, as water powers are gradually developed and applied to the common network, because no capitalization of the water rights on the public domain will be permitted. The rates and issuance of securities will be, in general, under the jurisdiction of commissions—commissions which already have jurisdiction as to the issuance of securities in some of the Western states, and in effect they have it in all cases, because no company would think of issuing securities for new construction unless it was with the assurance that the public would allow such a rate as to enable it to pay the interest on such securities.

We are at the threshold of a new era. The passage of a water power law which will attract capital to new hydroelectric enterprises, the creation of a community of interest through interconnection of systems into large networks and the intelligent co-operation of the utilities, the commissions and the public, which will be brought about thereby, will result in the rapid upbuilding of an industrial West.

Switching and Protection of Transmission Circuits

S. Q. Hayes
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Westinghouse Electric & Mfg. Company

THIS ARTICLE discusses in a general way some of the principal features of switching and protection of power transmission systems. It deals principally with oil circuit breakers, relay equipment, lightning arresters, station layouts and system arrangement. A few high-voltage transformers used on some of the larger systems are described, and attention is called to a few other of the more important features. The term "power transmission" will be limited in this article to generating stations where practically all the power is stepped up by transformers and very little is distributed at the generated voltage. This practically limits the article to plants furnishing power at 22 kv and above.

TRANSFORMERS for step-up service at the generating station and corresponding step-down service at other points may be either single-phase or three-phase, naturally or artificially cooled. Water-cooled transformers are usually employed on the larger systems, where water is available. The relative advantages of the different types cover too broad a field to be discussed at length in this article. The main advantages claimed for single-phase transformers are based on the fact that a spare unit is of only one-third the size of a spare unit for three-phase service, and that, where the transformers are operated in delta, one of the three can be cut out of service and the two remaining units still furnish three-phase power. Where transformers are star connected on the high-tension side, as is usual practice, this latter advantage cannot be claimed.

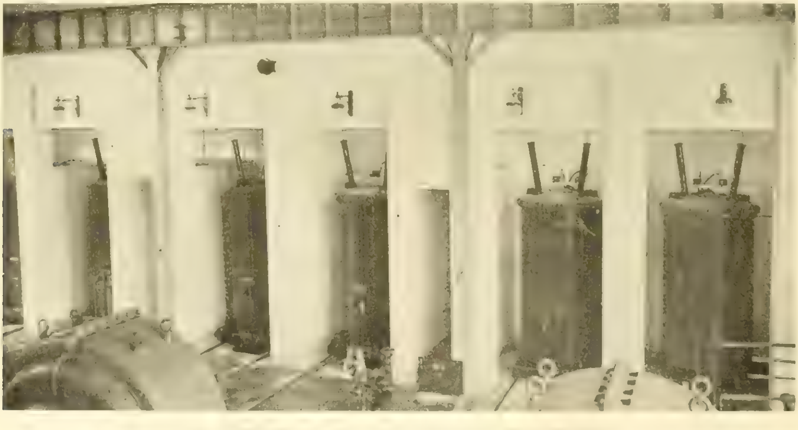


FIG. 1—GROUP OF 4400 KV-A, 115 000 VOLT TRANSFORMERS
Installed in the generating station of the Inawashiro Hydro-Electric Power Company, Japan.

Where the number of transformer circuits does not exceed two or three, single-phase transformer banks with one spare normally cost somewhat less than the corresponding number of three-phase transformers with a three-phase spare unit. When there are more than three transformer circuits, three-phase units with one spare transformer may be cheaper. A point is reached, however, in the construction of transformers of large capacity, where there is no appreciable saving in the cost of the three-phase over three single-phase units, each of one-third the capacity. In certain cases, the question of shipment and handling at destination may make it imperative to utilize single-phase units. In general, for transformer circuits of more than 15 000 kv-a. capacity, three single-phase units will be preferable to one three-phase unit.

The natural cooled transformers are made in plain cases up to a certain capacity, depending upon the voltage and frequency, and beyond this size it is desirable to employ transformer cases of fluted construction or with external radiators, in order to obtain the additional cooling surface required to dissipate the heat caused by the transformer losses.

Artificially-cooled transformers of the air-blast type have been built for voltages up to 25 000, and have been employed principally in city service where fire regulations prevented the use of oil-insulated transformers. Even with oil-insulated transformers of the self-cooling type, an air blast has occasionally been utilized to assist in carrying off the heat.

Most of the artificially-cooled transformers in America are oil insulated and the cooling is obtained by means of water circulating through cooling coils placed under the oil near the top of the transformer tank. In a few instances, however, in America and a large number of cases in Europe, oil circulation has been adopted, the oil being withdrawn from the transformer tank near the top, passed through an external cooling device and then delivered to the transformer near the bottom. As a rule, the water-cooled transformers are somewhat cheaper than transformers for forced oil circulation, if the external cooling equipment for the transformers is included in their costs.

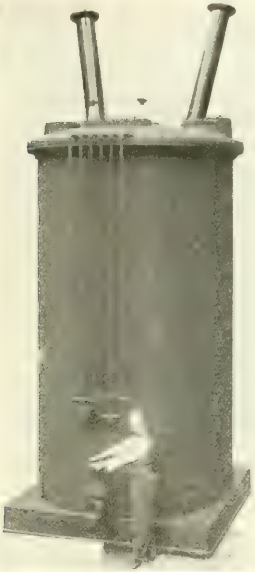


FIG. 2—5833 KV-A, 150 000 VOLT SINGLE-PHASE TRANSFORMER
Installed at the Big Creek Power Station of the Southern California Edison Company.

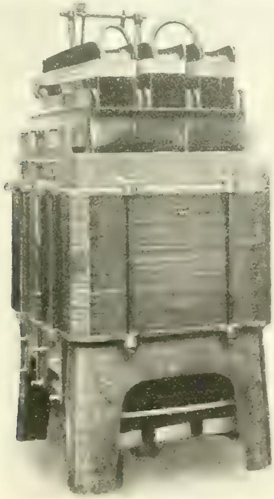


FIG. 3—COILS AND IRON OF THE TRANSFORMER SHOWN IN FIG. 2

Transformers of the various types mentioned can be made either for indoor or outdoor service, but during the last few years probably 80 percent of all high-voltage transformers built in America have been arranged for outdoor service. In some cases, where new generating stations have been installed on old power systems, the new equipment was supplied with indoor transformers and indoor high-tension switching, in order to correspond with some of the old installations.

Whenever any comparatively level space is available adjacent to the generating station, outdoor transformers and outdoor switch gear, with the concrete foundation and the steel work necessary for the busbars and wiring, usually work out much cheaper than the corresponding indoor equipment. It occasionally happens, however, particularly where a hydro-electric generating station is located in a gorge, that no level space can be found near the station suitable for a transformer and switch yard, and in such cases indoor transformers and indoor switch gear, even with the building to house them, may prove to be the best arrangement.

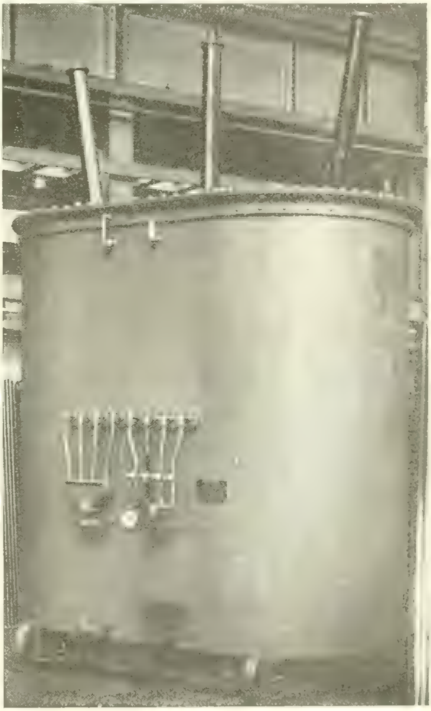


FIG. 4—10 000 KV-A, 107 000 VOLT THREE-PHASE INDOOR TRANSFORMER
Installed at the Holter plant of the Montana Power Company.

A portion of the indoor transformer equipment installed by the Inawashiro Hydro-electric Power Co. in Japan, is shown in Fig. 1. The generating station contains twelve 4400 kv-a., 6600-115 000 volt, single-phase transformers, oil insulated, water cooled, connected in four banks of three each, delta-delta, while at the Tokio receiving station there are twelve 4000 kv-a. oil-insulated, water-cooled transformers stepping down from 100 000 volts to 11 000 volts.

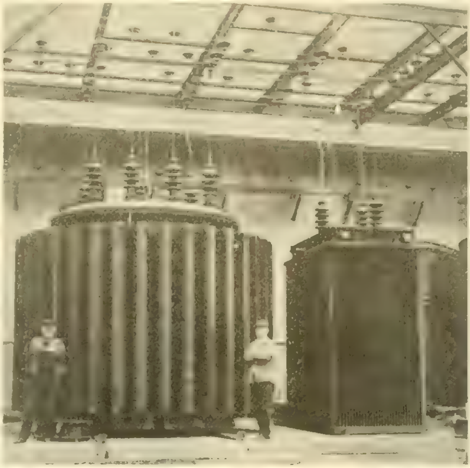
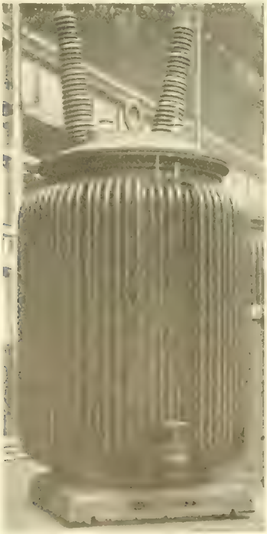


FIG. 5—5000 KV-A SELF-COOLING RADIATOR TYPE, AND 1000 KV-A SELF COOLING FLUTED CASE TRANSFORMERS

Installed at the West Farms station of the New York, New Haven & Hartford Railroad, for outdoor service.

When this plant was installed, Japanese regulations would not allow outdoor transformers to be utilized for extra high-voltage. Due to the shipping limitations over a narrow gauge railway it was necessary to build these transformers with tanks of comparatively small diameter for their output. The transformers are each located in a separate compartment and arranged so that they can be rolled out into the generating station to be handled by the overhead crane. The structure containing the low-tension bus-bars and circuit breakers is located back of the transformers, while the high-tension switchroom is above the transformers.

One of the six 5833 kv-a. transformers furnished to the Big Creek power plant of the Southern California Edison Co. is shown in Fig. 2, three of these transformers being used in a group in connection with a 17 500 kv-a. generator stepping up from 6600 volts delta to 150 000 volts star, with an arrangement for grounding the neutral of the star of the generating station. Power is transmitted to Los Angeles, a distance of 275 miles. These transformers are among the largest and highest voltage transformers ever built for indoor service for single-phase. Fig. 3 shows the coils and iron of this transformer, indicating the staunchness of the bracing and the general substantial structure.



[illegible] 10 000 [illegible] TANK TYPE SELF-COOLING [illegible] TRANSFORMER

Installed by the Southern Power Company.

One of the four 12 000 kv-a. normal, 16 000 kv-a. maximum rated, three-phase, water-cooled transformers furnished for indoor service at the Holter plant of the Montana Power Company stepping up from 6600 to 107 000 volts is shown in Fig. 4. The fact that the balance of the generating stations on the Montana Power Company's system were arranged for indoor service made it advisable to have the Holter Plant arranged in the same manner. In this transformer the water-cooling coils are brought through the side of the tank below the oil level to facilitate complete drainage of the coils.

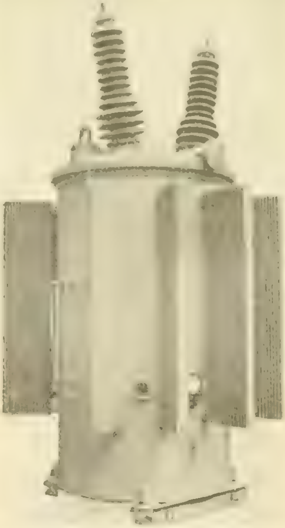


FIG. 7—2500-5000 KV-A., 132 000 VOLT, SINGLE-PHASE OUTDOOR TRANSFORMER

Installed at the Washington, Pa., substation of the West Penn Power Company.

Two types of outdoor self cooling transformers are illustrated in Fig. 5, supplying power to the New York, New Haven & Hartford Railroad. The 5000 kv-a. transformers furnish the energy across the phase normally used for railway service, while the 1000 kv-a. unit is a teaser transformer to obtain three-phase power. These transformers are installed outside the West Farms station, where power is received from the circuits of the New York Edison Company.

One of the tubular type self cooling transformers furnished in the year 1908 to the system of the Southern Power Co. is shown in Fig. 6. These were among the earliest high capacity transformers intended for outdoor

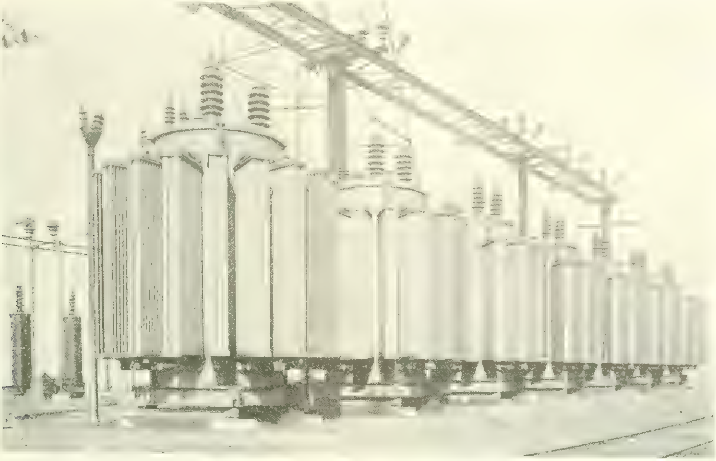


FIG. 8—GROUP OF 8333 KV-A, 66 000 VOLT, SINGLE-PHASE, RADIATOR TYPE TRANSFORMERS

Installed at the Brunots Island plant of the Duquesne Light Company.

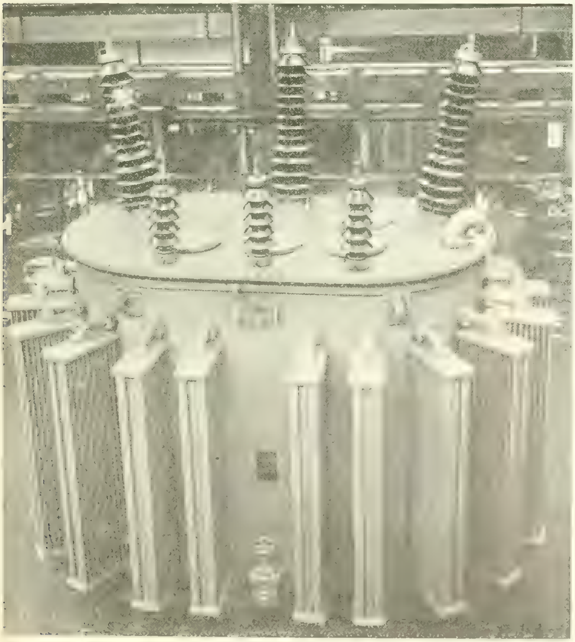


FIG. 9—3000 KV-A, 125 000 VOLT, THREE PHASE, RADIATOR TYPE SELF-COOLING, OUTDOOR TRANSFORMER

Installed by the Catalana Gas & Electric Company, Spain.

FIG. 10—10 000 KV-A, 132 000 VOLT, SINGLE PHASE, WATER COOLED, OUTDOOR TRANSFORMER

Installed at the Windsor station of the West Penn Power Company service. This tubular type of large capacity self cooling transformer has been practically superseded by the radiator type shown on Fig. 7. This transformer has a rating of 2500 kv-a. as a self cooling unit, and 5000 kv-a. as a water cooled unit for 60 cycle service and forms part of a bank used at the Washington, Pa., substation of the West Penn Power Co. for tying together their 132 000 and 27 000 volt systems. The water piping system is brought out through the side of the tank at such a point as to permit a complete drainage of the water cooling coils in case the transformer is to be out of service for any considerable length of time during the winter.

An installation of seven 8333 kv-a., 66-38.1-22 kv, 60 cycle, single-phase, radiator type transformers is shown in Fig. 8, which were furnished for the Duquesne Light Company in 1919 for their Brunots Island Plant. These are among the largest, single-phase, radiator type transformers supplied for outdoor service down to the present time.

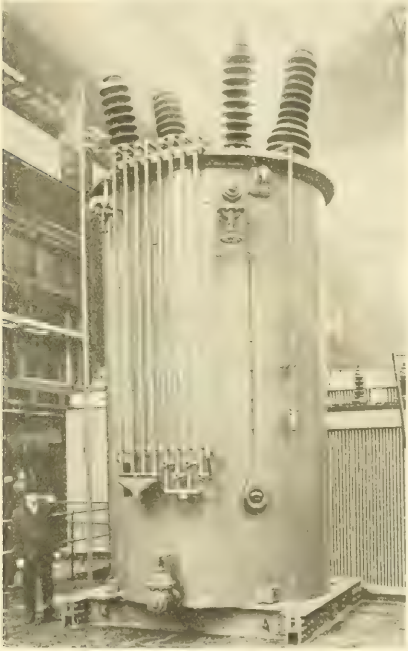


FIG. 11—11 500 KV-A, 150 000 VOLT, SINGLE-PHASE, WATER-COOLED OUTDOOR TRANSFORMER

Installed by the Southern California Edison Company.

The radiator type transformers are also built for three-phase service. Fig. 9 shows one of the 3000 kv-a., 125-50 kv transformers connected star-star, tying together the 60 cycle systems of the Catalana Gas & Electric Company, in Spain.

Outdoor transformers are also built as water-cooled units for both single-phase and three-phase. Fig. 10 shows one of the three 10 000 kv-a. 13.2-132 kv, single-phase, outdoor type, water cooled transformers furnished in 1917 for the Windsor station, supplying power to the lines of the West Penn Power Co. In this transformer the water cooling coils are brought out through

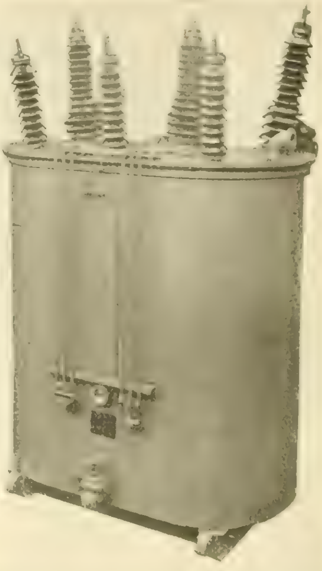


FIG. 12—4000 KV-A, 152 000 VOLT, THREE-PHASE, WATER-COOLED OUTDOOR TRANSFORMER

Installed by the Sierra Construction Company.

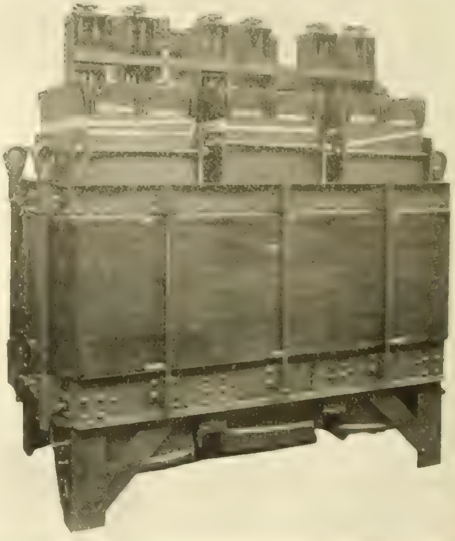


FIG. 13—IRON AND COIL ASSEMBLY OF A 17 500 KV-A, 100 000 VOLT, THREE-PHASE, WATER-COOLED, OUTDOOR TRANSFORMER

Installed at the Wateree station of the Southern Power Company.

the side of the tank below the oil level to permit complete drainage of the water from these coils if the transformers are to be shut down during the winter time. Fig. 11 shows one of the eleven 11 500 kv-a. 150-72 kv single-phase transformers star connected, high-tension and delta low-tension, installed in 1919 by the Southern California Edison Co. for tying together their 150 kv and 72 kv transmission systems. Fig. 12 shows one of the 4000 kv-a., 152 400-95 200 volts, three-phase, outdoor type water-cooled transformers, core type, connected star-star, installed in 1918 by the Sierra Construction Co.

The coils and iron assembly of one of the five 14 000 kv-a. 40 degree rise, 17 500 kv-a. 55 degree rise, three-phase, water-cooled transformers furnished for the Wateree generating station of the Southern Power Company are shown in Fig. 13. The high-tension coils are connected in star with arrangements for grounding the neutral when desired. The illustration shows the method of bracing employed.

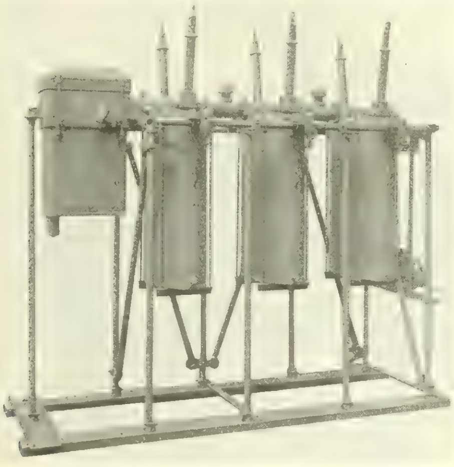


FIG. 14—37 000 VOLT OIL CIRCUIT BREAKER FOR INDOOR SERVICE

OIL CIRCUIT BREAKERS

The main oil circuit breakers used for power transmission service are built for either indoor or outdoor use, depending on whether the transformers with which they are employed, are arranged for indoor or outdoor service. While the circuit breakers used in the low-tension circuits of the transformers play a vital part in the power transmission, this article will be limited to the high tension circuit breakers intended for operation at 22 kv or higher.

Practically all such circuit breakers are arranged for solenoid operation as three-pole units, and most of them are built with a separate steel tank for each pole. Usually these steel tanks are so arranged that their spacing may be made to suit the wiring of the installation in case the minimum spacing normally used would introduce undesirable bends in the wiring. As practically all of the high-tension circuit breakers here considered can be made suitable for either indoor or outdoor service, but are usually supplied for outdoor, most of the illustrations and descriptions will apply to the outdoor type of equipment, but enough indoor apparatus will be illustrated to show the essential differences between the two types.

Up to 73 kv, the high-tension oil circuit breakers, whether for indoor or outdoor service, are usually made frame mounting to permit the tanks to be easily dropped to secure rapid inspection and adjustment of the contacts. Fig. 14 shows a 37 kv, circuit breaker for indoor service and clearly illustrates the pipe framework used for supporting it at such a height that the tanks can be readily dropped. The highest voltage circuit breaker that has been built for indoor service is shown in Fig. 15.

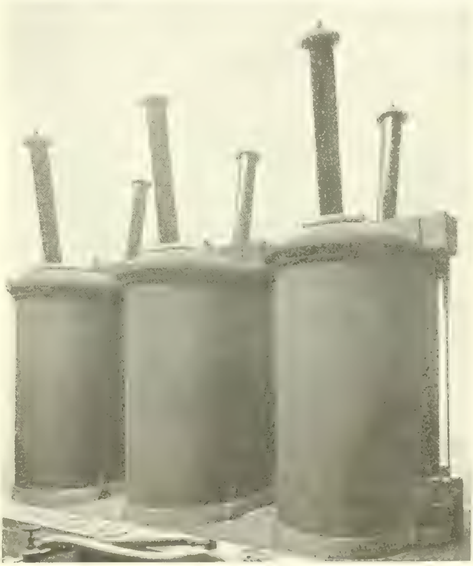


FIG. 15—150 000 VOLT OIL CIRCUIT BREAKER

Installed in the Big Creek station of the Southern California Edison Company.

Circuit breakers for high-voltage service, such as those illustrated, involve long travel of the contacts and heavy moving elements and therefore are arranged to embody a special quick break feature for the rapid separation of the arcing contact which is so essential on a high power interrupting device. Fig. 16 shows the contact details employed with the 150 kv circuit breaker. The lower end of the condenser terminal bushing is enclosed in a porcelain arc shield for protection from the arcs that arise during operation. Between this arc shield and the stationary contact is a metallic static shield for distributing the stress uniformly over the surface of the terminal bushings. The main contacts are of the butt type, each terminal having two main contacts and two arcing contacts, the latter being designed to take all of the arcing so that the main contact will not become pitted or burned by the arc. The entire stationary contact is enclosed in a metal hood, which distributes the electrostatic stress that might otherwise be excessive, due to the sharp corners on the edges of the contact mechanism.

The arcing contacts attached to the stationary terminals are so arranged that in the closed position they are latched in touch with the corresponding arcing contacts on the movable member. When the circuit breaker opens, the main contacts separate at once, but the latch holds the arcing contacts together, forcing the upper one to be pulled down against the compression of a spring for a distance of approximately seven inches. After the moving member has dropped the seven inches, the latch releases and the spring retrieves the upper arcing contact, breaking the circuit very quickly.*

The break in the circuit occurs in the free oil and the natural tendency of the gas bubble to rise is not in any way impeded. The magnetic effect of the current passing down one stationary contact across the moving member, and back the other stationary contact is such as to blow the arc away from the contact and toward the side of the case. This effect, together with the natural tendency of the gas bubble to rise through the oil, enables the arc to be carried away quickly.

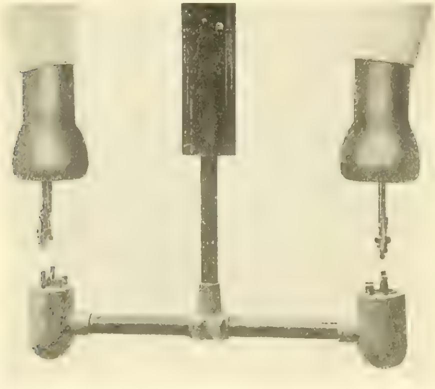


FIG. 16—CONTACT FRAMES OF CIRCUIT BREAKER SHOWN IN FIG. 15

While the descriptions that follow apply to outdoor circuit breakers, corresponding indoor units differ only from the outdoor ones in the omission of the rain shields from the condenser bushing terminals and certain minor changes in the housing of the mechanism and the venting of the tanks.

Fig. 17 shows a 400 ampere, 73 kv, solenoid operated, outdoor, frame mounting oil circuit breaker having a guaranteed rupturing capacity of 2400 amperes at 73 kv. This circuit breaker has elliptically shaped oil tanks made of steel plate with lap welded seams, and a cast-steel top of domed shape to secure ample strength against explosion. The tanks are arranged for suspension from the supporting frame and are hung by suitable tie bolts connected to a supporting grid beneath the tank. With the frame mounting it is possible to drop the tanks on any one pole to obtain ready access to the contacts. An overhung lip around the top is interlocked with the tank rim and suitable packing between the top and the rim insures waterproof joints. A suitable removable cover with interlocking rim gives access to the upper portion of the circuit breaker mechanism. Conduit pipe with packing washers and lock nuts affords weatherproof communication from pole to pole for the operating levers and for the control leads when required. The solenoid operated mechanism is located at one end of the unit, housed in a case or box with a removable cover having packed joints. This box has conduit pipe for connection to the circuit breaker mechanism.

The steel top, in addition to supporting and protecting the operating mechanism, is arranged to form an expansion chamber to cushion the pressure caused at the instant of interrupting the circuit. As considerable oil vapor and gas may collect in this chamber, suitable baffled vents are placed in such positions as to relieve sudden air pressures, and in addition, to induce circulation of air through the chamber to drain out the accumulating oil vapor. As the oil is of more or less volatile nature, this latter function is of considerable importance. To prevent the transmission of a disturbance in one tank to adjacent tanks and to the box containing the operating mechanism and solenoid, suitable baffles can be placed in the connecting conduit pipe. Pressure can be vented to the outside, but propogation of pressure from tank to tank will be prevented.

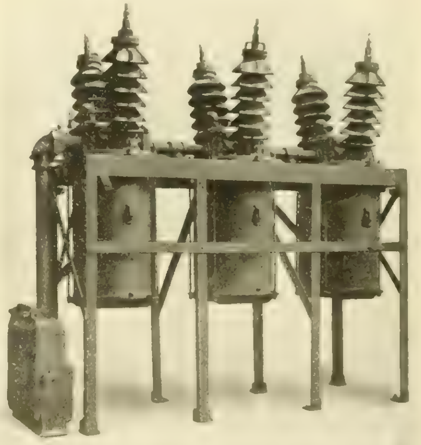


FIG. 17—400 AMPERE, 73,000 VOLT, FRAME MOUNTED, OUTDOOR TYPE [illegible]

The terminal bushings are sufficiently protected by petticoated insulators to afford insulation under the most severe conditions of driving rain, wet snow, or sleet. It is not uncommon to find the entire structure, including the exposed portions of the porcelain insulators, incased in a coating of sleet, or to see snow piled up practically to the entire height of the terminal bushings. Fig. 18 shows some outdoor circuit breakers that have been operating under wintry conditions. Under such conditions it is obvious that a considerable factor of safety in surface insulation is highly desirable and has been actually furnished in practice.

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*This action is described in detail in an article by L. R. Golladay, in the JOURNAL for April, 1918, p. 128.

On circuit breakers of small and moderate size where the weight of the oil tanks and oil is not prohibitive, the frame mounting arrangement of circuit breaker is highly desirable, as it permits the ready removal of the oil tanks for the purpose of inspecting the contact details and the operating mechanism without disturbing the line connections.

Circuit breakers for higher voltages and larger rupturing capacities are usually made platform mounting, owing to the difficulty of lowering the tank filled with oil. With the larger circuit breakers, access to the interior of the tanks is secured by the removal of the mechanism cap, which exposes the lever system and presents a sufficiently large opening to withdraw any necessary part. The mechanism is ordinarily so arranged that a terminal bushing, complete with its contact details, can be withdrawn without disturbing any other details, and the moving contact elements can also be withdrawn through the manhole or mechanism cover.

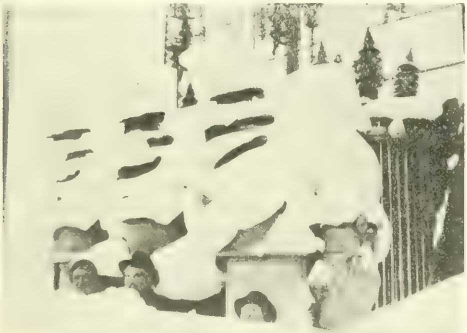

FIG. 18 OUTDOOR TYPE CIRCUIT BREAKER AFTER A SNOW STORM

Experience has indicated the desirability of providing a structural frame or platform that will permit access to the bottom of the tank, allowing free air circulation, as this assists in keeping all parts free from rust and corrosion. In certain cases the tank bases are made with openings in the rim, so that the bottom of the tanks can be painted with a long handled brush, if the foundation is of concrete or masonry that would otherwise make it difficult to get at the bottom of the tanks.

A typical outdoor platform mounted breaker is shown in Fig. 19, which illustrates a 95 kv, 400 ampere circuit breaker with elliptical tanks, having a guaranteed rupturing capacity of 2400 amperes at 95 kv. A number of these circuit breakers are employed at the Lakewood Transformer and Switching Station of the Southern Power Co., and at other points on that system.

This company employs different types of oil circuit breakers at different points of their system, depending on rupturing capacities and other requirements, so some of the other types will be considered here to facilitate comparisons. At their latest hydraulic plant—the Wateree Station—five 14 000 kv-a. generators feed through their individual three-phase transformers into the 100 kv system. The low-tension leads running to the transformers are controlled by indoor oil circuit breakers located in the basement of the power house, with connections so made that normally each generator supplies current to its own transformer and the units are not in parallel on the 6600 volt bus.

The high-tension side of these transformers is controlled by means of the outdoor, electrically operated circuit breakers with flat sided tanks shown in Fig. 20. An idea of the size of these circuit breakers may be obtained from the fact that the man on the left is a six footer. A side view of these same circuit breakers, with the overhead disconnecting switches, is shown in Fig. 21, and a general view of the switch yard is shown in Fig. 22. One very interesting feature of the switch yard where these circuit breakers are installed, is that it consists of a concrete platform set up on concrete pillars at such a height as to be beyond the flood level. This outdoor switch yard is located on the bank near the station end of the dam, and the 110 000 volt leads from the three-phase transformers are carried diagonally across the tail race and pass through the five flat sided circuit breakers to the busbars.

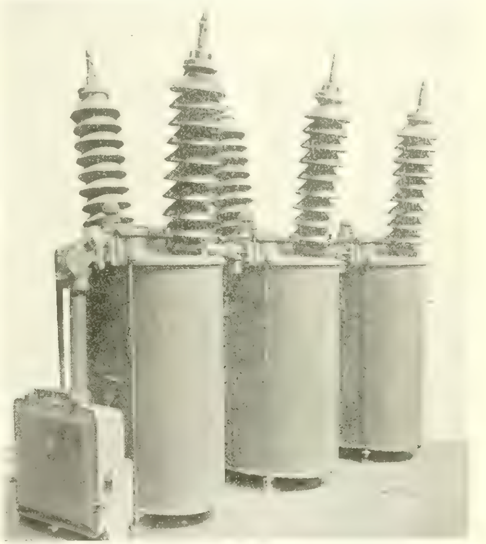

FIG. 19. 400 AMPERE, 95 000 VOLT, FRAME MOUNTED, OUTDOOR CIRCUIT BREAKER

Installed at the Lakewood switching station of the Southern Power Company.

The outgoing line circuits from this station are controlled by means of the round tank circuit breakers shown in Fig. 23. These oil breakers are provided with circular tanks having domed top and bottom, and were guaranteed capable of rupturing 3750 amperes at 115 000 volts, while the flat sided transformer circuit breakers have been guaranteed capable of rupturing 3290 amperes at 110 000 volts.

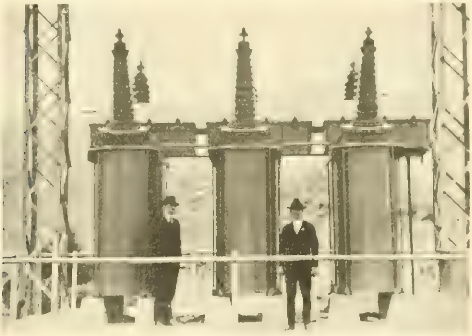

FIG. 20—110 000 VOLT, OUTDOOR TYPE, OIL CIRCUIT BREAKER
Installed at the Wateree station of the Southern Power Company.

The engineers responsible for the design of the two different types of breakers illustrated have been working along very different lines to secure high rupturing capacity. With the transformer circuit breakers, flat side tanks are used, but the arc is broken under the oil in a special explosion chamber shown in Fig. 24. The function of this explosion chamber is based on the theory that by confining the arc to a restricted space a high pressure will be developed, tending to blow the oil out of the explosion chamber down on the moving contact, forcing the arc away from the contact and causing its rapid extinction. The steel cylinder forming the explosion chamber can be readily made of ample strength for the pressure developed. As the bottom of this explosion chamber is open to the oil to permit the movement of the contact and as oil is practically incompressible, it would seem that the pressure developed inside the explosion chamber would be communicated to the walls or the bottom of the tank, and that the stresses to be borne by the tank would be practically independent of the functioning of this explosion chamber.

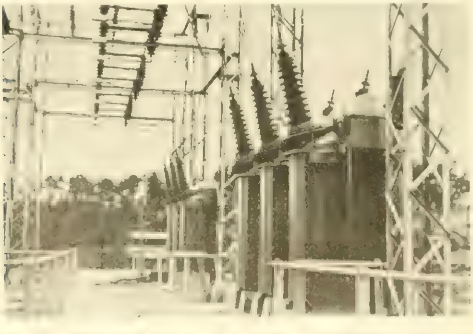

FIG. 21—SIDE VIEW OF CIRCUIT BREAKERS SHOWN IN FIG. 20

The type of circuit breaker furnished for the outgoing line circuit is provided with circular tanks, having domes at top and bottom, employing heavy boiler plate construction; thus forming tanks capable of withstanding internal pressures as high as 150 lbs. per square inch. This circuit breaker is provided with condenser bushing terminals of the type shown in Fig. 25, consisting essentially of a tube or rod forming the conductor and surrounded by a number of concentric condensers of predetermined capacity, arranged in such a manner as to secure a practically uniform potential gradient from the inner one, forming the line conductor, to the outer one, which is grounded to the case of the transformer, circuit breaker or lightning arrester.

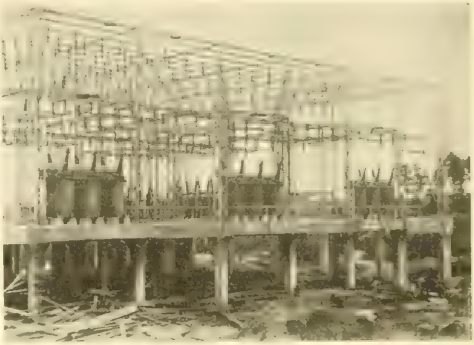

FIG. 22—SWITCH YARD AT THE WATEREE STATION OF THE SOUTHERN POWER COMPANY

Where the bushing is used for transformers, the end operating in the oil is provided with a metal terminal of spherical shape and when used in circuit breakers, this shape is approximated as closely as practicable with the form of contact used in the circuit breakers. The standard test of the condenser bushing is 2.5 times the working voltage, and in addition, when the switches

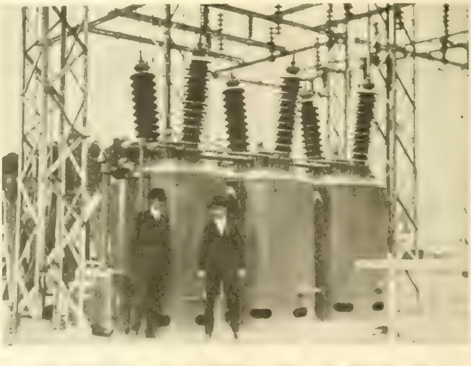

FIG. 23—115 000 VOLT OUTDOOR TYPE CIRCUIT BREAKER
Installed at the Wateree station of the Southern Power Company.

are used on outdoor service, a further test is made of twice the line voltage under a spray of water, at one-fifth of an inch per minute, directed at 45 degrees from the vertical, the test lasting for one minute.

All of these condenser bushings have a comparatively long grounded portion, and it is usually feasible to place current transformers over the bushings and utilize these for the automatic operation of oil circuit breakers. The lower portion of the bushing, when used with an oil circuit breaker, is covered by a porcelain arc shield.

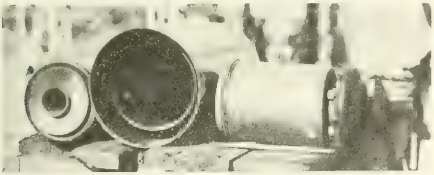

FIG. 24—EXPLOSION CHAMBER OF CIRCUIT BREAKER SHOWN IN FIG. 20

To minimize the corona under the oil, the stationary contact, shown in Fig. 26 is provided with a barrel shaped cap shown to the left of the contact. This practically does away with any sharp edges that would otherwise tend to form corona. These circuit breakers for high voltage service embody the special quick break feature for the rapid separation of the arcing contact previously described.

As an example of a slightly older design of floor mounting or platform mounting type of circuit breaker, Fig. 27 shows a 400 ampere, 115 kv, three-pole, outdoor type of which a large number were furnished for the Inawashiro Hydro-electric Company in Japan, and a number of practically identical units have been supplied to various power companies in America. This circuit breaker, in a slightly modified form, has a guaranteed rupturing capacity of 2400 amperes per phase at 115 kv. Each pole is located in a separate elliptical steel tank with the bottom outside welded, and provided with a re-inforcing rim. The dome shaped top provides ample space for the operating mechanism and a baffled vent is located in this top for discharging any gas that may be formed. The spacing of the poles can be readily modified to suit the wiring of the installation, as the only mechanical connection between the adjacent poles is a simple pull rod running through a pipe connecting together the operating mechanism of the individual poles.

FIG. 25—CONDENSER TERMINAL OF THE CIRCUIT BREAKER SHOWN IN FIG. 23

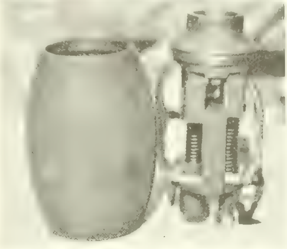

FIG. 26—STATIONARY CONTACT AND CORONA CAP OF CIRCUIT BREAKER SHOWN IN FIG. 23

Fig. 28 shows a 400 ampere, 135 kv electrically operated, oil circuit breaker having a guaranteed rupturing capacity of 1600 amperes at 135 kv. A number of these units are in service in Michigan.

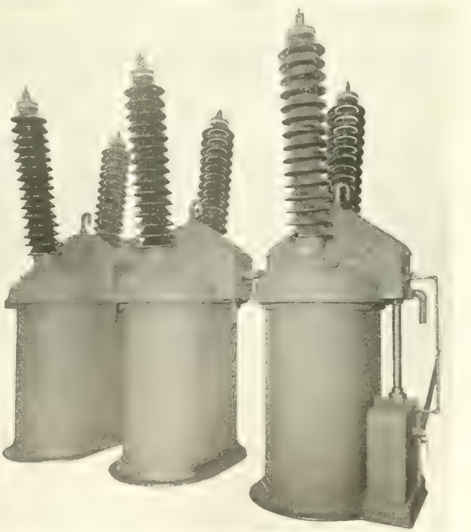

FIG 27—115 000 VOLT, 400 AMPERE, OUTDOOR CIRCUIT BREAKER
Installed by Inawashiro Hydro-Electric Company, Japan.

Where even greater rupturing capacities are desired for high voltage service, the circuit breaker tanks are made circular with domed top and bottom, employing heavy boiler plate construction and in this manner tanks are obtained capable of withstanding pressures as high as 150 pounds per square inch. Fig. 29 shows a 400 ampere, 135 kv, three-pole circuit breaker of this type, having a guaranteed rupturing capacity of 4300 amperes per phase at 135 kv. This circuit breaker was furnished to the West Penn Power Co. for 132 kv service and a modification of it is available for 155 kv service. Designs have been prepared for circuit breakers for use on 220 kv circuits, but none have been built up to the present.

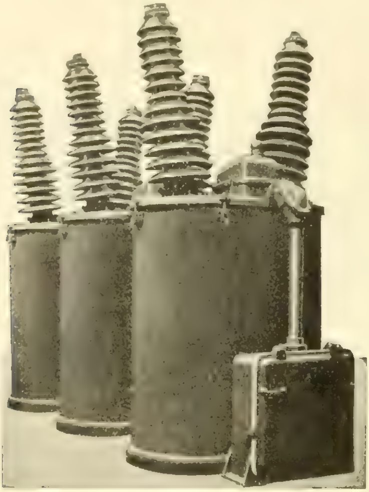

FIG. 28—135 000 VOLT, 400 AMPERE, OUTDOOR TYPE, OIL CIRCUIT BREAKER

Having a guaranteed rupturing capacity of 1600 amperes at 135 000 volts.

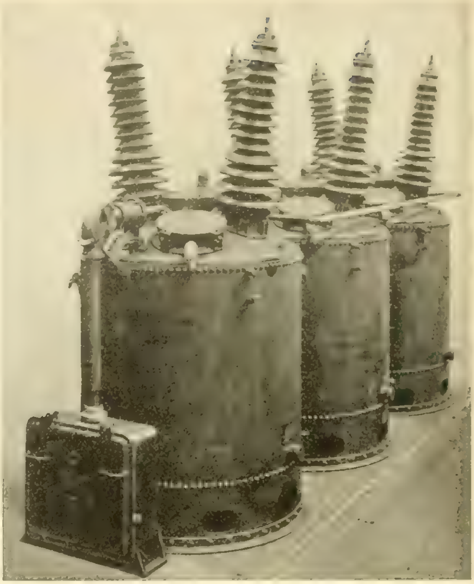

FIG. 29—135 000 VOLT, 400 AMPERE, OUTDOOR TYPE, OIL CIRCUIT BREAKER

Having a guaranteed rupturing capacity of 4300 amperes per phase at 135 000 volts.

(To be continued)

Industrial Electric Heating

Wirt S. Scott
Manager, Industrial Heating Section,
Westinghouse Electric & Mfg. Company

INDUSTRIAL ELECTRIC HEATING for temperatures under 600 degrees F received its initial start in the automobile industry about four years ago, and the impetus it has attained is due largely to the character of this industry. Not having any ancestral ideas to influence them as to the way in which a given operation should be performed, it was easy for them to adopt a new method of doing things. In the second place, there is no industry that knows so accurately the manufacturing costs of every item entering into the completed product, hence competive tests on trial installations, were quite certain to be accurately and completely made. It is highly significant that practically all of the automobile companies in this country have discarded their gas-heated ovens for electrically-heated ovens.

The question immediately arises—"What are the advantages of electric heat over other forms of heating?" The one predominating question that was asked several years ago, and is still occasionally asked is "What does it cost?" The latter question cannot be answered until the first question has been taken into consideration, and the importance of each item carefully weighed as to its effect on quality of product, labor, operating conditions, and finally the effect on the cost of the completed product.

CLEANLINESS

The collection of dirt and dust on a product while being dried or baked may not be detrimental to its quality, but this is seldom the case. All work that is given a protecting or finishing coat of paint, varnish, lacquer or enamel is impaired by the collecting of dust on its surface. A speck of dirt one can scarcely see with the naked eye is magnified many times when coated and baked, and becomes a blemish where a high polish is desired. With coal, gas or oil fuels, the hot gases, in most cases, come directly in contact with the work, depositing the products of combustion on the wet surface. A few attempts have been made to use muffle-type ovens in which the work is indirectly heated, but these are unsatisfactory, due to high first cost, excessive maintenance, and non-uniformity of temperature. Where the fuel is burned directly in the oven, a large volume of air must be blown into the oven to supply sufficient oxygen for combustion. Unless the air is washed before entering the oven, it will carry a large amount of dust in with it, some of which will be deposited on the work. The air, entering the oven under high velocity, will set in motion small particles of dirt that inevitably collect, regardless of the pains to keep the ovens free from dust. With electric heat, no air is required for combustion nor are carbonaceous products of combustion formed, and the amount of ventilation required can be restricted to the very minimum.

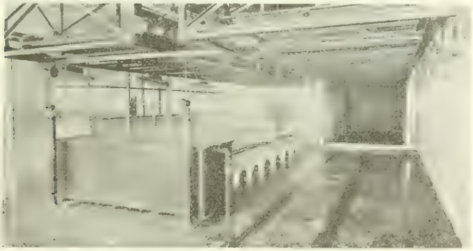

FIG. 1—ONE OF A GROUP OF SEMICONTINUOUS, CONVEYOR TYPE OVENS IN AN AUTOMOBILE PLANT

The dip tank, with the cover closed, is shown in the foreground. The work is dipped and hung on the conveyor where it drips before baking.

SAFETY

Regardless of the safeguards placed around gas ovens, they continue to explode. It seems to be the irony of fate that, when one boasts that he has never had an explosion in one of his gas ovens, he is due for one in a short while. In one case, a manager of a plant, who made the boast that gas ovens could be operated as safely as electric ovens, became alarmed, and put on an inspector whose only duty was to light the gas burners, and to see that they were burning. An explosion took place within a very short while, due to the oven becoming filled with escaping fuel gas, resulting in a very serious explosion, a number of employees injured and considerable property damage. Very explicit directions can be given to an employee as to what he must or must not do when lighting a burner in an oven, but no way has been yet devised to convert a human being into an automatic machine. So long as ovens are heated by means of an explosive mixture, just that long will there be fires and explosions in ovens. With electric heat, it is evident that all danger of fires and explosions due to explosive fuels is eliminated.

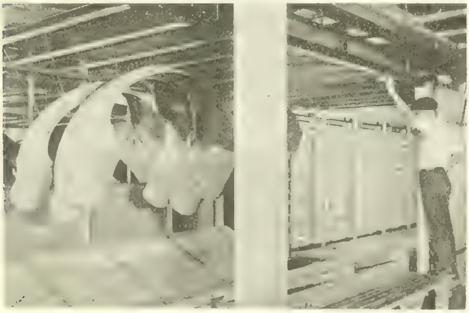

FIG. 2—AUTOMOBILE FENDERS READY FOR BAKING

The operator is shown in the act of starting the conveyor which will carry the work into the oven.

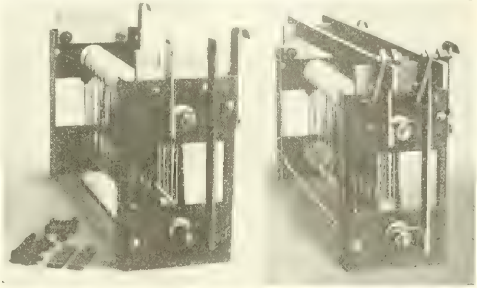

FIG. 3—OVEN HEATERS WITH BUS-BARS, INSULATORS, CONNECTORS AND MOUNTING HOOKS

The view at the left shows the heater before the bus-bars are installed. The unique features of this type of heater are, the bus-bars are mounted directly on the heater, standard connectors are used for connecting from the heater to the bus-bars, bus-bar clamps are used in place of drilling and bolting the connectors, heater hooks are used for hanging the heater to supporting straps, and a protecting wire screen may be attached directly to the upturned flanged end forms for the protection of the heater and bus-bars.

UNIFORMITY OF TEMPERATURE

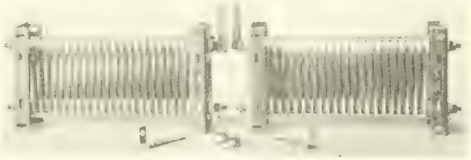

FIG. 4—2.5 KW. 110 VOLT OVEN HEATERS

Two heaters are shown in series for 220 volt service. Four or five heaters may be connected in series for 440 or 550 volts respectively. The heaters are 21 in. long, 6 in. deep and 10 in. high.

An electrical installation is made up of a number of heating elements, depending upon the capacity required to produce the baking results desired. Due to their flexibility and ease of installation, they can be placed on the floor or the side wall, or wherever desired. It is often impossible to predetermine exactly where the heaters should be located, in order to produce uniform temperature throughout the oven in the box type of oven, where this is essential; or to produce a gradual increase in temperature, in the continuous conveyor type of oven, if after a trial test, it is found that uniform temperature or proper graduation of temperature is not obtained as desired, it is a simple matter to disconnect a few heaters at the point where the temperature is too high, and move them to the place in the oven having a low temperature. This flexibility of installation is one of the great advantages of electric heat, as it is evident that no other form of heating lends itself so readily to this adjustment to existing operating conditions.

AUTOMATIC TEMPERATURE CONTROL

With the use of electric heaters in ovens, a cleaner and purer atmosphere within the oven makes it possible to obtain a finish that is not sprinkled with blemishes, the danger due to explosions of gas fuel is eliminated, and by proper location of the heaters, uniformity of temperature throughout the oven is obtained. The use of the electric heater, in itself, did not, however, prevent the oven temperature from steadily climbing beyond the baking temperature and ruining the work. It is a frequent occurrence with gas ovens, and was, at first, perhaps, as equally frequent with electric ovens, for the operator to forget to cut off the heat at the proper time, with the result that when the oven finally received his attention the temperature would be several hundred degrees higher than the baking temperature. If the finish was not ruined, the product was greatly impaired, and while the overbaking perhaps could not be detected by visual inspection, the life of the enamel would be gone, and a few months of exposure to the weather, combined with the jarring and strains to which an automobile is subjected, would cause the enamel to flake off.

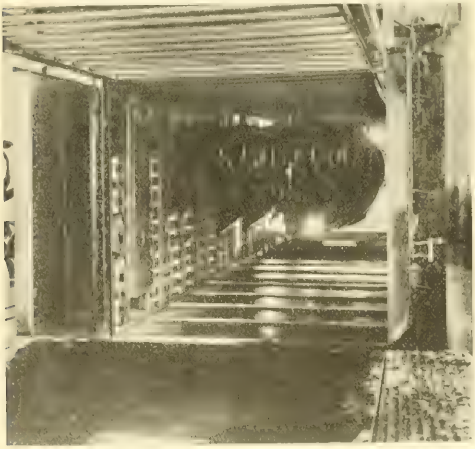

FIG. 5—A SEMICONTINUOUS CONVEYOR TYPE OVEN FOR BAKING ENAMEL ON AUTOMOBILE FENDERS

With this type of oven, the fenders are dipped in the enamel by hand and hung up on the conveyor to drip. The conveyor extends into and through the oven, returning over the top. After dripping, the work is run into the oven, the work which had been in the oven being carried out on the conveyor at the same time. While a batch of work is baking, another is being dipped and hung on the conveyor ready for baking, as soon as the bake already in the oven has been completed. Heaters are mounted along the sides of the oven.

It was not until the automatic temperature control was developed that the full benefit of electric heat was realized. This control consists of a thermostat which operates magnet switches, through which power to the heaters is supplied, energizing the heaters when the temperature of the oven drops to a predetermined value, and cutting them off when the temperature reaches a predetermined maximum value. The thermostat can be set so as to hold the temperature within a range of five degrees F plus or minus. Ovens are in daily operation requiring no more work or attention than is given to the electric lights that illuminate the enameling room. A button is pressed to turn on the

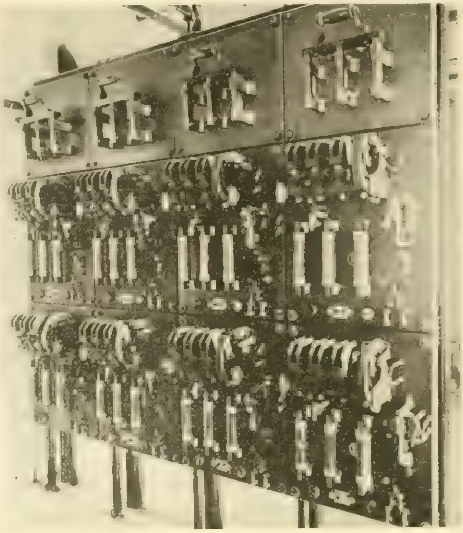

FIG. 6 FOUR SECTION AUTOMATIC TEMPERATURE CONTROL PANEL
For four semicontinuous conveyor type ovens.

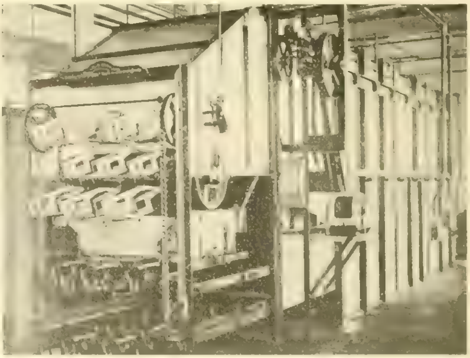

FIG. 7 A CONTINUOUS CONVEYOR TYPE ELECTRIC OVEN

Suitable for baking enamel on typewriters, fans, small motors, automobile license tags, small castings and sheet metal work of various sizes and shapes. The work is hung on the conveyor, and is carried over a pulley down into a tank filled with enamel, up and down through a dripping space and then through the oven. The conveyor travels in an up and down direction as it progresses through the oven, returning near the floor and under the heaters. In the illustration, three rods of the conveyor are shown filled with typewriter frames before they have been dipped, and two rods after the frames have been baked and are coming out of the oven. Automatic temperature control is essential to the successful operation of this type of oven.

current, the ovens coming up to the proper temperature, and remaining there until the "off" button is pressed at the end of the day. Very frequently, where long baking periods are required, an oven is loaded just before quitting time, and the current cut off by means of a time clock several hours later.

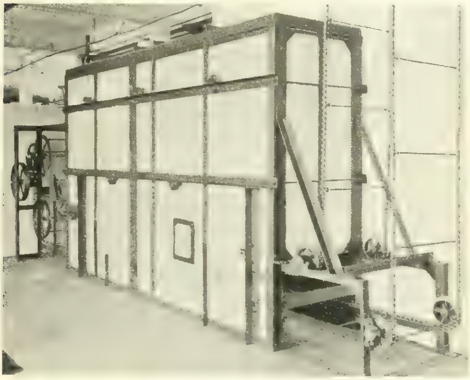

FIG. 8—A CONVEYOR TYPE OVEN FOR BAKING SMALL PIECES

This oven is loaded at one end, the conveyor coming out the opposite end and carrying the work up to the floor above where it is taken off.

REDUCTION IN LABOR

Labor is a serious problem, and any apparatus that will save labor is worth installing, if it does nothing else. Practically all the improvements made along this line in connection with oven work have been made since the adoption of electric heat. An important advantage of the electric heater is due to the fact that it lends itself almost ideally to the conveyor type of oven. In a conveyor type oven the work is carried continuously through the oven, entering the oven at room temperature, and being gradually heated in order that the metal and enamel will come up to temperature uniformly, thereby obtaining the maximum amount of adhesion between the metal and enamel; driving the solvent out of the enamel slowly and uniformly, so that craters formed in driving out the solvent have sufficient time to flow together and close, giving a smooth homogeneous surface before it takes a permanent set. The work finally enters the baking section of the oven, where the temperature is held within narrow limits. It is the coming practice to dip and bake the material automatically with one handling of the work, regardless of the number of coats to be applied. Installations are now being made for three and four coats of enamel, all dipped and baked automatically in one continuous operation. The work is handled but twice, once when the pieces are hung on the conveyor before they are dipped in the first coat of enamel, and again, when they are taken off the conveyor after the final baking in the last oven. With this arrangement, a half dozen men will do the work ordinarily required of 50 or 60 men. While the saving with small conveyor type ovens may not be proportionate, it is more than sufficient to justify their use. One oven installed in a typewriter factory made very substantial savings in labor, and a second equipment is now being installed at the same plant. With the automatic temperature control equipment, an appreciable amount of labor is saved in attention to the oven temperature. The workmen can give their undivided attention to the real object of their employment—getting material through the oven.

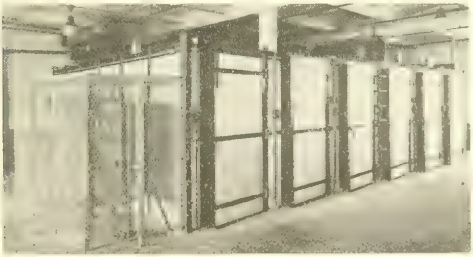

FIG. 9—A BANK OF SIX OVENS FOR BAKING LITHOGRAPHING ON METAL BOTTLE TOPS

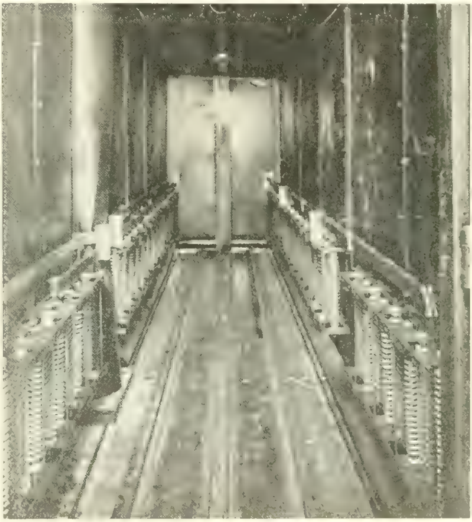

FIG. 10—INTERIOR OF ONE OF THE OVENS SHOWN IN FIG. 9

Heaters are installed along the side wall of each oven in the manner indicated, and baffle plates placed in front of them. Ventilation pipes, running the full length of the oven, under the heaters, force air through the heaters which, on being heated, is blown into the oven across the work being baked. The air is drawn off at the ceiling by means of air exhausters. 80 percent of the air is returned to the oven, under the heaters, the balance being exhausted to the atmosphere. The temperature is maintained constant, by an automatic system of control, consisting of magnet switches operated by means of thermostats through suitable relays. Door switches are provided, so that upon opening the door of any oven, the heaters and exhauster for that particular oven are cut off.

IMPROVED PRODUCT

Improved product is due to the elimination of dust in an oven, the proper location of heaters in an oven, and close control of temperature. The elimination of

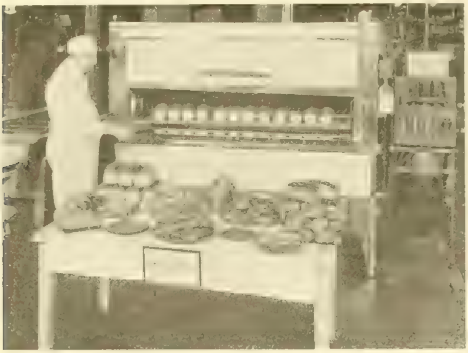

FIG. 11 A REVOLVING TYPE ELECTRICALLY HEATED BAKE OVEN

With automatic temperature control, for baking bread, pies, cakes and pastries. Twelve oven heaters of the type shown in Fig. 3 are installed in the bottom of the oven, giving a capacity of 30 kilowatts. The oven holds 96 one-half pound loaves of bread, which are baked in 35 minutes.

dust permits obtaining a smooth surface on the work. A uniform temperature, properly controlled, produces a piece of work that is neither over or under baked, having been baked at a predetermined rate, consequently its lasting qualities, such as retaining its luster and adhering to the metal, especially when subjected to the weather, are uncomparably better than when baked by the hit and miss process.

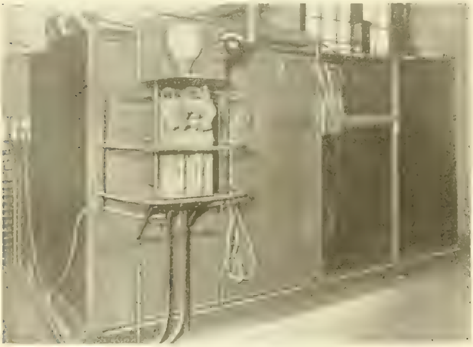

FIG. 12 ELECTRIC OVEN USED FOR BAKING ARMATURES AT A STREET RAILWAY REPAIR SHOP

A standard line of ovens and equipment has been developed for this work. This particular oven is 5 ft., 6 in. wide, 6 ft. high and 12 ft., 8 in. long, inside dimensions, with a door opening of 4 ft., 4 in. wide by 5 ft., 8 in. high. The oven will accommodate twelve large armatures and has a capacity of 50 kilowatts. A recirculation ventilating system is used, the air being drawn off at the floor and returned into the oven again at the ceiling. 75 percent of the air is recirculated, the balance being exhausted to the atmosphere. Automatic temperature control is used.

As mentioned in the first part of this article, low temperature industrial heating received its start in the automobile industry, and latter proved its value. This method of heating has branched out so rapidly into other lines that it is a safe prediction that in ten years the gas oven will be as obsolete as the gas engine is now in the industrial plants.

There are also wonderful possibilities in the field of heating from 2300 degrees F down. This includes forging furnaces, brass melting furnaces, hardening furnaces, tempering and annealing furnaces, sherardizing furnaces, ovens for baking and drying, blueing of steel and air tempering, oil tempering baths, solder and babbitt melting pots, liquid heaters of various kinds, space heaters for heating tanks, rolls, hot tables, etc., and air heaters for various purposes. Apparatus as above outlined is being developed and it is hoped that equipment will be available in the near future for all such purposes.

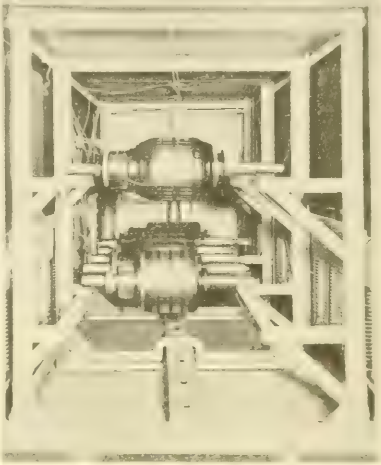

FIG. 13 INTERIOR VIEW OF OVEN SHOWN IN FIG. 12

The question often arises,—"Where do you find any application for industrial electric heating?" The answer to that question is—In almost every industrial plant. If you don't believe it, just inquire at the next half dozen plants you visit.

The Irrigation of the Desert

E. B. Criddle
General Agent,
Southern Sierras Power Company

*"The wilderness and the solitary place shall be glad for **them,** and the desert shall rejoice and blossom as the rose"*

EVERYONE ATTENDING the N. E. L. A. Convention this year, will be keenly interested in the story of the part electric power has played in the development of Southern California, and the marvelous production of fruits, vegetables, grains, cotton and livestock to feed and clothe a hungry nation and a needy world. Not very many years ago, millions of acres of what is now this great garden of the Southwest were arid desert wastes where not a sprig of green could be seen excepting sage brush and cactus, grease-wood and gramma grass or perhaps Joshua trees. One cannot but marvel at the transforming power that has made such changes possible on so vast a scale; and while in the final analysis God must be recognized as the one comprehensive cause. God works through men in this world, and men have harnessed God's power and made it work these new wonders.

Ever since man awoke to the necessity of providing food, clothing and shelter for himself and his kind, he has dreamed dreams of better days and states of habitation, and ever since men have dreamed such dreams and talked about them the idea of transforming a desert into a garden of Paradise has been abroad in the world. But, although the reclamation of desert lands is no new thing, the Egyptians having flooded the thirsty sands with the muddy waters of the Nile and converted them into fertile farms away back in the days of the early Pharoahs, while even on this continent, in Mexico, in Arizona, and in other places, prehistoric irrigation ditches have been found, yet never have operations been carried on over so extensive an area or with such marvelous results as here and now in Southern California.

These former desert lands embrace, among others, the now fertile valleys of the San Joaquin, Owens River, San Fernando, San Jacinto, Perris, Coachella, and the Great Imperial Valley, where alone the turbid waters of the Colorado River are made to irrigate more than 500 000 acres of what were formerly shifting sand dunes, but last year yielded products worth upwards of $65 000 000.

Practically all of this wonderful Southland, radiating like a fan from Los Angeles to and beyond the San Bernardino Mountains on the north, eastward to the Colorado River and stretching away southward to San Diego and the Mexican Border, was formerly a desert. Now these same lands are producing alfalfa, milo maize, barley, wheat, broom corn, Kentucky hemp, cotton, wool, beef cattle, hogs, sheep, poultry, dairy products, oranges, grape fruit, lemons, apricots, peaches, pears, strawberries, dates, figs, raisins, grapes, melons, honey, olives, almonds, walnuts, head lettuce, asparagus, peas, tomatoes, onions, spinach, beans, sugar beets, cauliflower, and many other varieties of food and agricultural products in enormous quantities.

When the early Missionary Fathers and their followers landed on the shores of the Pacific and wandered inland, they found that, wherever a stream of water was available, the Indians were irrigating as much of the land as might be required. Later, the white men extended the limited areas thus irrigated until, more recently, great irrigation districts or reclamation projects were formed and water applied to as large an extent as the available supply, within reasonable distances, permitted. But until hydro-electric energy was transmitted hundreds of miles from the High Sierras of Mono and Inyo Counties to these southlands, millions of acres, which have since been made to rejoice and blossom like the rose, remained barren trackless wastes, although it was known that underneath these vast deserts were inexhaustible reservoirs of life-giving waters, renewed each year by the melting snows on the mountain tops.

The Southern Sierras Power Company has long been known as the "Desert Company", because through the building of the longest, direct high-tension transmission line in the world, from Bishop in Inyo County and Rush Creek in Mono County to San Bernardino and thence south to the Perris and San Jacinto Valleys and southeast through the Coachella Valley to the Imperial Valley and the borderland of Mexico, this Company not only supplies light, heat and power to the prosperous communities and people whose thriving cities and fertile ranches are now to be found where once there was only a desert, but the Southern Sierras Power Company and its associate companies of the Nevada-California Electric Corporation have played a very large and important part in bringing about this wonderful transformation. Acres and acres of arid lands have been irrigated by waters from underground reservoirs delivered to the fields by electric power-driven pumping plants. Cheap hydro-electric power has made possible the profitable irrigation for alfalfa, grain, and deciduous fruits with water not only 25 feet below the surface of the ground but 125 feet, while lemons are grown by irrigation where the available water is lifted more than 600 feet by electric power generated over 300 miles away.

Thirty-five hundred horse-power is required to operate the jumping plants supplied with electric power from the high tension lines of the Southern Sierras Company in the Perris Valley, 1600 hp. in the San Jacinto Valley and 850 hp. in the wonderful date-growing Coachella Valley. In addition there are larger pumping plants with an installed capacity of 1000 hp. at Redlands, and 300 hp. at the Lytle Creek Water Company's plant at San Bernardino, furnishing water for orange growers in the Rialto section, and numerous similar installations scattered over the irrigated areas of Southern California.

In other sections further east and north the Southern California Edison Co., Pacific Gas & Electric Co., and the San Joaquin Light & Power Co. are all supplying the hydro-generated electric energy for delivering water to now fertile and highly productive lands which were formerly barren. At Colton the two great systems of The Southern Sierras Power Company and The Southern California Edison Company are interconnected, making possible the maintenance of a balance of power between these companies and consequently enabling each to render better service. Before this article is published, the transmission of electric energy throughout the length and breadth of the state will probably have been accomplished by the bridging of the fifteen mile gap between the lines of the Pacific Gas & Electric Company and the San Joaquin Light & Power Company, thus establishing a remarkable flexibility of distribution and interchange of current to meet the acute shortage of power in the Northern part of the state this year.

FIG. 1—CATTLE RANCH IN THE IMPERIAL VALLEY
An irrigation ditch is shown in the lower left hand corner.

In addition electricity plays a large part in the preparation of the products of these irrigated lands for market. In packing houses and canneries, fruit is sorted, distributed, washed, cooked, hulled, chopped and labelled by electrical machinery. Cotton is ginned and oranges and lemons are packed in boxes made by nailing machines, operated at low cost by electric power.

Although the famous Imperial Valley is irrigated by gravity waters from the Colorado River through a net work of canals comprising the most remarkable irrigation system in the world, here, too, electric power has played and is playing a most essential part, not only in the marketing of the abundant products of the soil but in making living conditions more tolerable under the extreme heat of the summer months. The Imperial Ice & Development Co., a subsidiary of the Nevada-California Electric Corporation, having three plants at Brawley, El Centro and Calexico, as well as a fourth plant at Coachella, manufactured last year 78 000 tons of ice by hydro-electric power transmitted nearly 500 miles, the consumption of current for this purpose being upwards of 6 000 000 kw-hr. Ice is supplied to the people of these valleys but is required principally for icing refrigerator cars of perishable fruits and vegetables which can thus be shipped to the great markets of the east, carrying a breath of sunkist freshness and vitality from this wonderful southland to the tables of a vast portion of the population of the country during the months when they would otherwise be dependent on the can-opener. This season 3000 cars of lettuce, spinach and asparagus requiring 28 000 tons of ice were shipped and ice is now being stored for shipping ten to twelve thousand carloads of cantaloupes to be shipped during the coming season.

The marvelous fertility of the soil of the Imperial Valley is due in a large measure to the rich silt containing minerals and other fertilizing products deposited on the land each year by the irrigating waters of the Colorado River. But at Hanlon Heading, where the Imperial Irrigation District maintains a large intake for supplying water to the valley, so heavy are the deposits of silt that it is necessary to operate four large dredges in order to keep the main canals open. These are all electrically driven, the installation totalling 2762 horse-power; Hanlon Heading is 510 miles from The Southern Sierras Power Co.'s Mono County generating plant on Rush Creek.

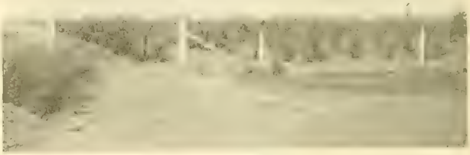

FIG. 2—DATE FARM NEAR HOLTVILLE

Thus in this way, also, cheap hydro-electric power is an essential factor in the now marvelous productivity of the great American desert. In other ways too, it adds comfort and increases efficiency by lightening the burdens of people who live and work in the valley. Much of the cooking is done by electricity, and new electric ranges are being installed constantly, together with other modern electric devices which lessen the heat of household labors, including electric flat irons, mangles, washing machines and fans. The reclamation of the desert is no longer a dream but a wonderful reality, and the pioneering courage and spirit which have brought this to pass made it possible for America not only to send vast quantities of food and clothing abroad during the war but likewise places upon us a responsibility of continuing these shipments to the starving people of Europe and the Near East.

Ornamental Street Lighting

L. A. S. Wood
Manager, Illuminating Section,
George Cutter Works, South Bend, Indiana

IN THE early days of electricity, street lighting design was a simple problem, the solution of which generally took the form of arc lamps at street intersections; but with the growth of the "City Beautiful" idea, progressive cities demanded more ornamental lighting fixtures and the elimination of unsightly overhead equipment. Thus "ornamental street lighting" became a slogan.

Ornamental street lighting schemes usually originate with groups of progressive citizens, and advantage is often taken of the engineering experience of manufacturers of street lighting devices who prepare detailed reports and recommendations which enable the citizens to form an estimate of the cost and upkeep of a suitable system. The proposition is then handled in the same way as a municiple paving scheme, an "Improvement District" is created and an assessment made on the property owners to cover the cost of the improvement. In other cases, the city will undertake the installation and maintenance of ornamental systems in important business sections, or the merchants in the section will subscribe the necessary funds, on a front foot basis, for the installation and the city will undertake the maintenance.

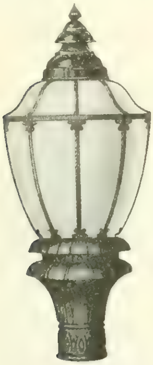
FIG. 1 EGYPTIAN TOP

FIG. 2 SOL-LUX TOP

In designing a street lighting system four fundamental factors should be considered, viz:—

1—Type of lighting unit.
2—Height of unit above sidewalk.
3—Method of supporting lighting unit.
4—System of operation.

Other factors, such as width of streets, type of streets (business or residential), character of adjacent buildings, distance from substation, etc., must also be taken into consideration.

The introduction of the high efficiency Mazda C lamp, with the almost total elimination of the arc lamp, has made ornamental street lighting possible and many beautiful designs in ornamental lighting units, posts and brackets have been placed on the market, some of which are illustrated in this article.

Ornamental street lighting units may be divided into two classes, the suspension and the upright type. The latter are used on ornamental posts and on trolley brackets, as shown in Figs. 3 and 5, while the former are used on taller posts as shown in Figs. 7 and 8.

On business streets where there are no trolley poles, ornamental posts of the type shown in Fig. 3, are usually adopted and the decorative effect of such a post is thoroughly in harmony with the "City Beautiful" idea. These posts are designed to bring the light center of the unit from 10.5 ft. to 15 ft. above the sidewalk, and at these mounting heights, diffusing glassware should be used in the lighting unit, as otherwise glare will result. Glare within the range of vision of the pedestrian or vehicle driver should always be avoided. It causes the pupil of the eye to contract in an effort to protect the delicate mechanism of the retina, thus preventing the observer from seeing as well as he would be able to do with a light source of lower intensity but more perfect diffusion. We are conscious of this phenomenon when entering a moving picture theatre from a street flooded with sunlight,—at first no details can be seen but gradually when the eye becomes accustomed to the light, or in other words when the pupil becomes dilated permit-

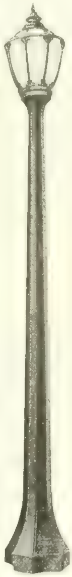
FIG. 3 ARCADIAN POST

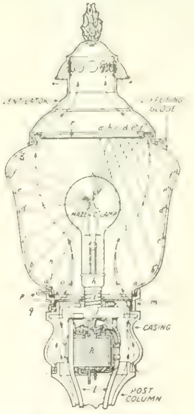

FIG. 4 SECTIONAL VIEW OF
SOL-LUX UNIT
Showing internal reflectors.

ting more light to enter the eye, the interior details become visible.

With upright units or "post tops" the best distribution on the lighting plane is obtained from units with internal reflectors, such as shown in Fig. 4, but if a more decorative effect is desired with increased illumination in the upper hemisphere to bring out the details of adjacent buildings, units of the type of the Egyptian top shown in Fig. 1 may be used, or the "Sol-lux" top, Fig. 2, may be equipped with a glass canopy instead of the metal ventilator. Round ball globes are not recommended on single light posts.

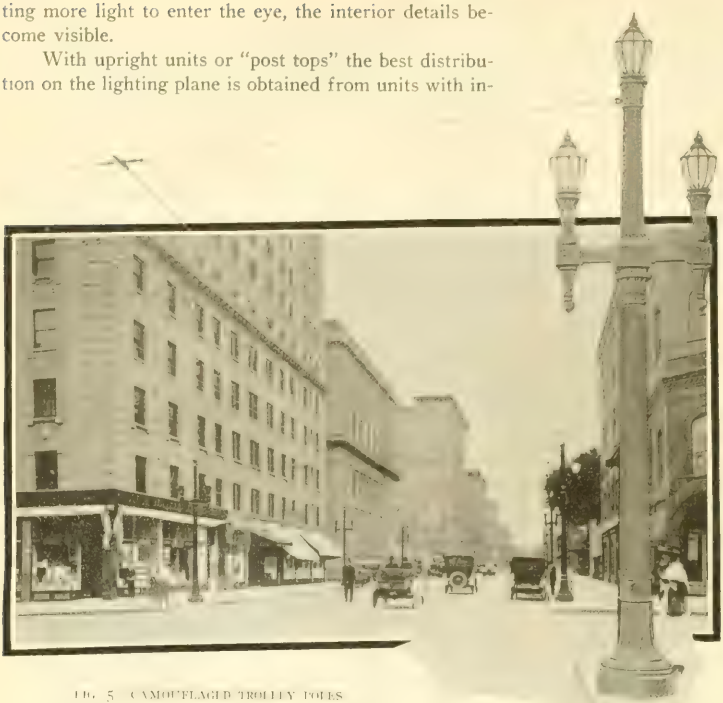

FIG. 5—CAMOUFLAGED TROLLEY POLES

In cities where street lighting of a less ornamental character is desired, taller posts with pendant units, such as shown in Figs. 7 and 8, may be used. In these cases, the units are mounted from 18 to 25 ft. above the sidewalk, and may be equipped either with diffusing glassware or refractors. At this mounting height the intrinsic glare of the refractor unit is not objectionable and excellent distribution on the lighting plane is obtained with a corresponding increase in distance between posts.

One of the most difficult problems which faces the illuminating engineer, when laying out a modern street lighting system, is the presence of trolley poles along the streets, and it has been found very difficult to reconcile the purely utilitarian features of the trolley pole with the artistic requirements of an ornamental street lighting system.

Some progressive cities have solved the problem by removing the trolley poles and attaching the span wires to the fronts of the buildings; others have used the trolley poles as supports for ornamental lighting brackets, but neither of these solutions has met with general approval. The difficulty of obtaining permission from property owners to attach trolley wires to buildings has prevented the general adoption of the first scheme, and the second is objectionable in that the trolley pole still remains an

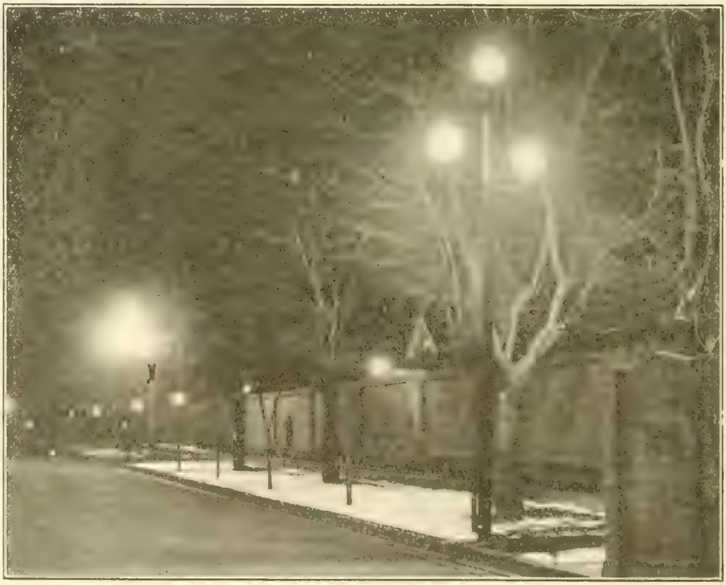

FIG. 6—NIGHT VIEW OF STREET SHOWING ORNAMENTAL BRACKETS ON TROLLEY POLES

unsightly but necessary evil.

A very satisfactory solution of this problem is shown in Fig. 5, illustrating a street lighting unit which completely disguises the trolley pole, while at the same time preserving its utilitarian character. The new ornamental trolley pole equipment consists of a hollow cast-iron column with bracket arms which is slipped over the existing trolley pole and so arranged that a maximum rake in the trolley pole of four inches can be concealed in the hollow column.

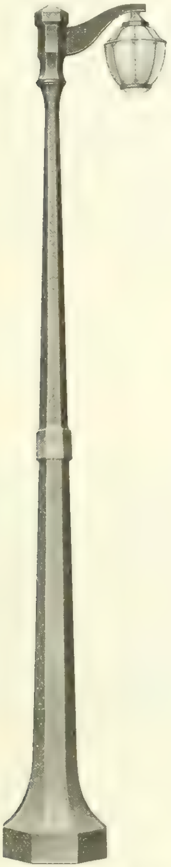
FIG. 7—ARCADIAN POST WITH EGYPTIAN LANTERN

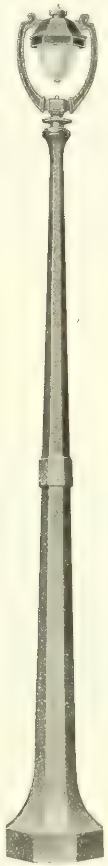
FIG. 8—ARCADIAN POST WITH MILWAUKEE LANTERN

For convenience in shipment and erection, the cast-iron column is made in four sections, viz., the base, the main column, the bracket section and the top column. Each of the sections is provided with an adjustable brace so that the whole can be set in alignment. The span wire is attached directly to the trolley pole by a ring bolt which passes through the top capital, and the strain caused by passing trolley cars is carried by the trolley pole and not the casing.

The method devised for wiring this equipment is very simple. The underground cable (usually steel-armoured lead-covered) is brought directly to the lower part of a disconnecting pothead set in the base of the pole where it is sealed with compound and efficiently bonded by two bonding clamps, as shown in Figs. 9 and 10. Lead-covered cables are then carried from the upper part of the disconnecting pothead between the pole and the casing to the lighting units. Access to the pothead is obtained through a door in the base of the column and wiring is facilitated by removable plates on either side of the brackets.

The height from sidewalk to the light center of the top unit is 22 ft. 9 in. and the height to the light center of the side units is 18 ft. 8 in. The artistic appearance of the camouflaged trolley pole can readily be seen and this equipment transforms an unsightly trolley pole into an ornamental lighting post, improving the appearance of the street in daylight and producing a brilliant "Whiteway" effect at night.

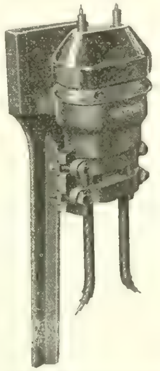
FIG. 9—DISCONNECTING POTHEAD

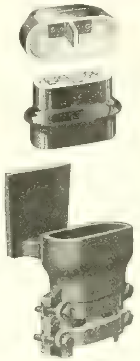
FIG. 10—DETAILS OF POTHEAD

Owing to its flexibility, the series system of distribution is usually adopted for ornamental street lighting. On such a system, lamps of 60 to 1500 candle-power may be used, thus permitting the candle-power of the lighting units to be varied in accordance with the requirements of their location and at the same time the whole circuit can be controlled from one point.

With the variety of ornamental street lighting fixtures now available the possibilities of efficient and artistic lighting for the "City Beautiful" are unlimited, and public spirited men who are guiding the destinies of American cities will find an easy solution to their problems by consulting the manufacturers of these devices, who have devoted many years of research to the design of suitable apparatus.

Notes on Industrial Lighting

OTIS L. JOHNSON
Illuminating Engineer,
Benjamin Electric Company

THE CONSERVATION of eyesight is of so much economic importance that six states have adopted lighting codes, and several others have tenative codes. All of these have one motive and that is the protection of the eyes of the workmen, for the authorities realize that most accidents in industrial plants are caused by dim illumination, glare (both direct and reflected), long sharp shadows and high contrasts.

The effects which must be attained by a modern efficient industrial lighting system are:—

1—Absence of both direct and reflected glare.
2—Sufficient intensity on all working surfaces, (horizontal and vertical).
3—An intensity of illumination on posts, walls and ceilings so as not to cause objectionable contrasts.
4—Good diffusion.
5—Light from the proper direction so as to avoid objectionable shadows.

GLARE

Glare is the biggest word of four letters in the illuminating engineers' vocabulary. Glare is dangerous; for it is positive in its harm. It destroys good eyesight, at first momentarily, temporarily, and then permanently. Beside that, as a large factor in wrong illumination, it is criminal in its effect upon health and as a drag upon production. Direct glare is light of high brilliancy in the field of vision. When light falls on polished surfaces or any surface from which it is reflected, the result is reflected glare. Reflected glare is often less obvious than that which comes direct from the light source, but it is usually much more harmful because of its insidious nature, in that it comes to the eye stealthily reflected from some polished surface. Since the eye is not guarded by nature from bright light or reflections from below, the detrimental effects of reflected glare are frequently more injurious than those of direct glare.

Reflected glare is harmful because of the fact that the eye is so often held directed upon such surfaces for long periods of time, and, while the glare may not be sufficiently annoying to be recognized as of a serious nature, it will undoubtedly in time produce eye fatigue or even permanent injury. Since the brightness of the reflected image is dependent upon the brightness of the light source, it follows that the harmful effects of specular reflection can be minimized by reducing the brightness of the primary light source. This can be done by using reflectors of large area with bowl enameled lamps or lamps equipped with some diffusing medium to prevent the direct light rays from striking the surfaces which cause the trouble. It is much more important to consider this point when designing the illumination of a machine or tool and die making shop, than it is for a carpenter or wood working shop, because the reflected images from metal are much more distinct than those from wood. Both direct and reflected glare must be avoided in order that the eyes may function properly.

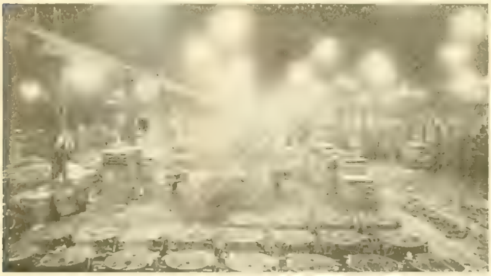

FIG. 1—NIGHT VIEW OF THE INTERNATIONAL HARVESTER COMPANY FOUNDRY

Using 300 watt Mazda C lamps, provided with top pole reflectors, placed 18 ft. above floor and spaced approximately 20 ft. apart.

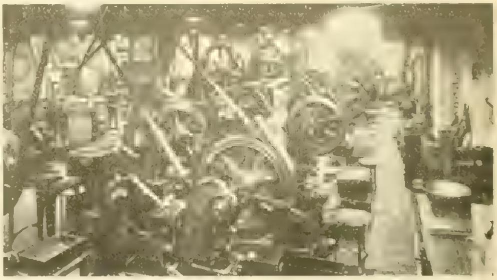

FIG. 2—ILLUMINATION OF PRESS SHOP

Using 75 watt Mazda C lamps, with opal caps and R. L. M. (reflector and lamp manufacturers) standard dome reflectors, placed 8 ft. 6 in. above the floor and spaced approximately 8 ft. apart.

"Safety First" has become more than a slogan, so it is reasonable to expect that since the preservation of eyesight is as important as the protection of limb, employers of labor will do all in their power to overcome this very prevalent abuse, and prevent the destruction of worker's eyes, which is so continual at present.

Glare forces the pupil of the eye to become small, thus admitting only a small amount of light. Eyestrain and fatigue follow, which in turn cause the workman to have headaches, to be nervous, restless, and inefficient. A general indisposition to work takes hold of a workman who is so unfortunate as to be the victim of these ailments. What is the result? Low production, spoiled material, wasted time, higher cost per unit of output, and more accidents. No enlightened factory management would think of allowing such effects to continue in his plant. Why not strike at the cause,—wrong illumination.

INTENSITY

Blindfold a skilled mechanic. How much work can he do? Provide him with dim illumination and he is able to do some work. But, in order that this skilled mechanic may work efficiently and economically, he must be provided with the right amount of the proper kind of light.

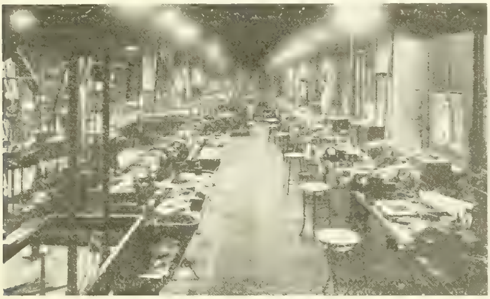

FIG. 3—NIGHT VIEW OF A MACHINE SHOP

Lighted with 100 watt Mazda C lamps and enameled bowl reflectors, placed 9 ft. above the floors and spaced 8 ft. apart.

Different industries and different operations of a given industry require varying intensities of illumination. Since the light which is really effective for purpose of vision is that which enters the eye from the object viewed, it is necessary to make the lighting system supply enough light to the object, so that the amount reflected from it to the eye will be sufficient for clear and comfortable vision. In other words, the brightness of the object is the vital factor, and this depends not only on the light received, but upon the reflecting power of the illuminated object. Materials vary quite widely in reflecting power. White surfaces reflect as high as 80 percent of the incident light, but black objects reflect only a fraction of one percent. Thus, light objects have high reflecting power and dark objects low reflecting power.

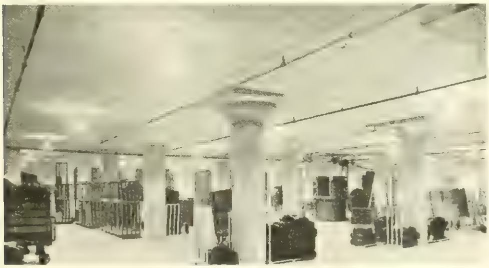

FIG. 4—STORAGE WAREHOUSE

Lighted with 200 watt Mazda C lamps, 10 ft. above the floor and 16 ft. apart, equipped with luminous top reflectors, with opal glass hoods, which diffuse a soft light upon the upper parts and ceiling of the room. This illumination of the area above the reflector rim adds to the apparent height of the ceiling and gives a cheerful effect.

When designing a lighting system for a given shop, careful attention must be paid to the average reflecting power of tools and materials. In a textile mill where only white goods are made, a certain intensity of illumination may be satisfactory, but if the goods are red, green or some other dark shade, a higher intensity will be necessary. For rough work, requiring no observance of fine detail, a moderate intensity is adequate; whereas, for fine work, such as weaving, the illumination must be strong enough to enable the operator to handle with ease the individual threads. In fine machine work, in which accurate measurements are made and tools must be set with great precision, a very intense illumination is required.

INTENSITY ON POSTS, WALLS AND CEILINGS

Care must be used in this regard, for an installation of good reflectors can be rendered almost useless it used under unfavorable conditions. In order that there shall not be a too high constrast of intensity between the work, the floor, and the post and walls, it is necessary to allow some light to fall upon them. Other conditions being correct, this will allow the eye to function properly, thus eliminating accidents which are caused by a workman not being able to take in his surroundings more or less subconsciously.

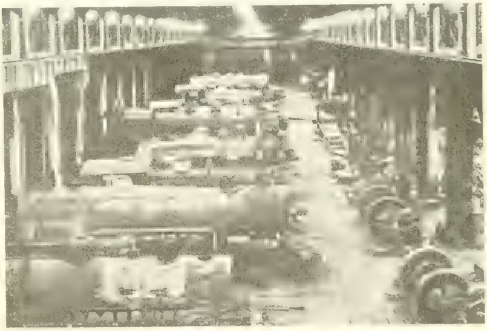

FIG. 5—QUEEN AND CRESCENT RAILROAD REPAIR SHOPS

The center row of lights consists of 1000 watt, Mazda C lamps, equipped with shallow bowl, porcelain enameled steel, ventilated reflectors, spaced 50 ft. apart. The lights at the side of the aisle are 500 watt Mazda C lamps, spaced 22 ft. apart, 23 ft. above the floor. They are equipped with porcelain enameled steel, elliptical angle reflectors, designed to distribute the light to one side, as well as along the aisle, giving light on the work from all directions and without glare.

An exaggerated example of what is meant by high contrast is that of automobile headlight lamps burning under daylight conditions, and then at night in the darkness. The lamps are hardly noticeable during the day because of the intensely illuminated environment, but at night, when darkness prevails, the glare is blinding to the eye. So care must always be used to see that all surfaces are so illuminated as to avoid dark backgrounds.

GOOD DIFFUSION

Diffused light is that kind which eliminates sharp, harsh shadows and permits the pupil of the eye to expand, so that the workman has high visual acuity, or distinctness of vision. Machines are never located so that they are in direct sunlight, for plant managers realize that diffused daylight is the best natural light by which to work. Light from the sky varies in color and intensity from morning till night. North sky light is most constant in both these qualities, which accounts for the fact that the majority of skylights face the north.

That system of artificial illumination which most closely approximates diffused daylighting is the best system of artificial lighting by which to work. This would mean a ceiling which is entirely luminous. This, of course, is impractical, but it gives color to one of the fundamental principles of good illumination which is, the installation of a large number of small light sources in preference to a small number of large ones.

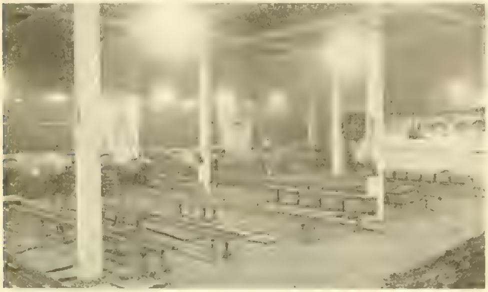

FIG. 6—BRASS FOUNDRY WITH DUST, GAS AND VAPOR PROOF SHALLOW BOWL REFLECTORS

Using 200 watt Mazda C lamps, 12 ft. above the floor and 16 ft. apart.

LIGHT FROM THE PROPER DIRECTION

It does not require a great amount of argument to convince any one that a workman cannot work efficiently when standing in his own light. He is at a great disadvantage and must necessarily work slowly, thus cutting down production, besides spoiling more material and raising the accident hazard. For these reasons, it is highly desirable to place lighting units so that no matter where machines or benches are located, they will receive light from the proper direction. When this is done, unsightly, inefficient, glare-producing localized or drop cord lighting is unnecessary, and the resultant illumination is of that type which protects the eyes, gives good diffusion, provides agreeable contrasts of intensity, and also provides each individual piece of work with light from several light sources.

Nearly all up-to-date industrial plants now have a Welfare Department, with a personnel which recognizes more and more the value of correct illumination as a means of improving the health and happiness of working people. When the lighting system is properly designed, a double gain is made, for in addition to a lot of improved men and women, the employer obtains:—

1. Increased production
2. Decreased costs per unit of output
3. Improved quality and less spoilage.
4. Fewer accidents

INCREASED PRODUCTION

Industrial plants use artificial illumination on an average of five hours per day, based on a year's operation. To be able to work at daylight efficiency during the time when artificial illumination is necessary is a distinct advantage, because of the resulting increase in production, which amounts to from eight to fifteen percent, as proven by actual production records.

On the basis of production in the United States, this means the services of 1 500 000 workmen who do not require food, clothing or a place to live, nor machines or places to put them. At this time when the cry "Increase Production" is heard around the world, it certainly seems fitting that every plant owner and manager should take steps to provide this dividend returning investment for his plant.

IMPROVED QUALITY

When superintendency is made easier and the workman is able to see his work distinctly and without eyestrain, less material is spoiled and better quality attained. A few years ago, a government report stated that out of $150 000 000 spoilage in the United States during the year, $28 000 000 was due to poor illumination. This amount would pay for many thousand installations of right lighting systems, and relieve our industries of a tremendous drain.

ACCIDENTS

Accidents cause suffering; they also cause loss of time already paid for by the employer. They lessen production; and many accidents are demoralizing to the entire working force. The employer bears the brunt of most of this loss, and also the loss due to the compensation which must be paid to the injured workman. Seventy-five percent of industrial accidents occur during hours of darkness or semi-darkness; more than one-fourth of these can be prevented by the installation of properly designed lighting systems. At a time when the man power of America is so very important—at a time when every ounce of effort must be made in industry—it is the duty of every manufacturing institution to provide artificial illumination which will prevent expensive and distressing accidents.

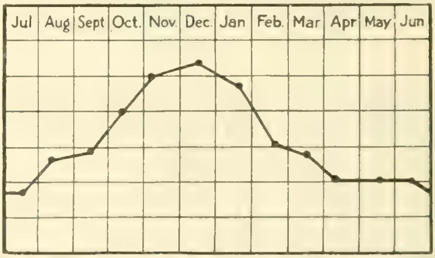

FIG. 7—MONTHLY CHART OF REPORTED FATAL ACCIDENTS FOR EACH YEAR

Adequate artificial lighting during the winter months would prevent many of these accidents.

This is not an academic question. These statements are conservative when viewed in the light of the facts as they are reported by eminent investigators and supported by repeated and authentic experiments. As an example, Mr. R. E. Simpson of the Travelers Insurance Co. states that 23.8 percent of 91 000 accidents investigated by his company were caused by improper or inadequate illumination. He further states that, "If we assume that only 18 percent of our industrial accidents are due to defects in the lighting installation, on that basis the services of 108 000 men for one year are lost annually in this country. That this condition should exist year after year is all the more reprehensible, because of the fact that the remedy is so easily applied and has beneficial results in many ways other than in the element of safety involved. Accidents caused by carelessness, inattention or ignorance can be elimented only by a long continued, painstaking, educational campaign, often involving a change in long established habits. The elimination of accidents due to inadequate or improper illumination is simply a matter of purchasing approved equipment and installing it under competent direction."

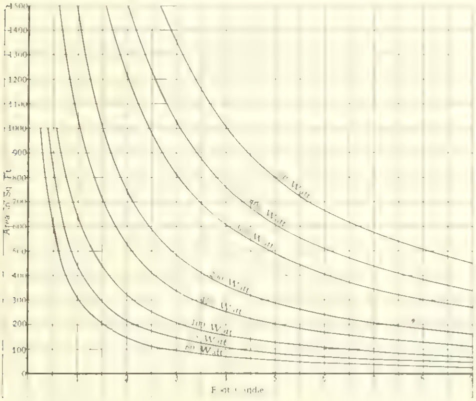

FIG. 8—RATIO OF LIGHT INTENSITY TO AREA ILLUMINATED

Based on the use of Mazda C lamps and Benjamin porcelain enameled steel reflectors and a utilization efficiency of 50 percent. From these curves can be determined the area which can be lighted to a given intensity with a given size lamp; or the intensity with which a given size lamp will light a given area; or the size of lamp which is required to light a given area at a given capacity. For example a 200 watt Mazda C lamp will light almost 500 sq. ft. to an intensity of three foot candles.

The necessity of proper illumination has been emphasized in the preceding paragraphs. Conditions vary so widely in different installations that it is impossible to go into details of exact design in a short article. However, bearing in mind all the facts heretofore brought out, the curves in Figs. 8 and 9 will be of service in designing a system of illumination which will give good results.

CONCLUSION

The equipment necessary for a system of lighting which complies with all the requirements of good illumination can be installed and operated for less than one percent of the average workman's wage. This sum is trivial when contrasted with the advantages. Good illumination is, therefore, not an expense but is an investment which pays large dividends.

Adequate factory illumination reduces eye strain, produces more cheerful surroundings, lessens fatigue in performing work, permits better order and neatness in the shop, allows more effective superitendency and management, results, in general, in approximately 25 percent reduction in preventable accidents and approximately 12 percent increase in production, these latter figures being dependent, of course, upon the previous condition of the factory.

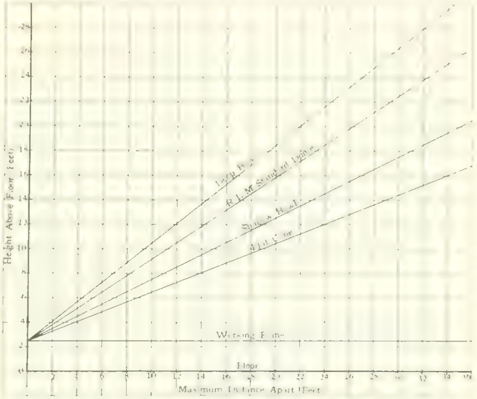

FIG. 9—RATIO OF MOUNTING HEIGHT TO SPACING FOR UNIFORM ILLUMINATION

This chart shows the maximum spacing allowable for any given height for each of the four chief types of Benjamin porcelain enameled reflectors. The spacing between reflectors when they are properly installed is in constant proportion to the mounting height. This ratio is the same for all reflectors for any one type, but the ratio of each type is different from that of the others. If the height and spacing are fixed, this chart will show the type of reflector which should be used to give uniform illumination. For a new installation, it can be used to determine the spacing for any desired height and type of reflector. Uniform illumination will be secured with any closer spacing than that indicated on the chart.

Don't judge illumination by the brightness of the lamps, but rather by the light on the object to be seen.

Don't work in a flickering light.

Don't expose the eyes to an unshaded light.

Don't work facing the light.

Don't use a bright light against a dark background.

Don't waste light by using the wrong reflectors.

Don't use shallow reflectors, which allow the lamp to be seen.

Don't let lamps, globes, or reflectors get dirty.

Don't save light at the expense of eyesight.

Steam for Extinguishing Fires in Turbo-Generators

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THE question of extinguishing fires in large turbogenerators is one of vital importance to operating men of today. The loss of a large unit, which is generally a large percent of the total capacity of the system, is very serious. A long time is required to get such a unit back in service, not only because of the time required for repairing the damage, but also because of that lost in securing repair parts from the manufacturers under present conditions.

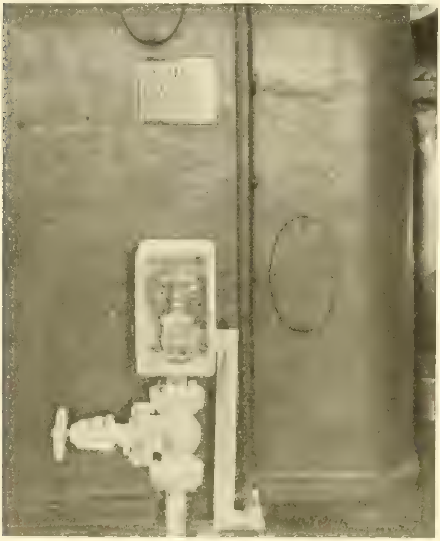

FIG. 1 LOCATION OF VALVES

Since the modern type of turbo-generator is entirely enclosed, and requires an enormous amount of air for ventilation, the method of extinguishing fires must be one that can be applied at the point where it is most effective with the greatest expedience. Steam and water are the two most common mediums used for extinguishing fires and the question of which is the better is still debatable. In the first method steam is used to smother the fire by the displacement of the air in the generator. In the second method water is used to saturate the windings, and thereby quench the flame.

In 1918, the Duquesne Light Company, of Pittsburgh, Pa., as a precautionary measure, installed a piping system to all its turbo-generators for using steam in extinguishing internal generator fires.

DESCRIPTION OF EXTINGUISHERS

The extinguisher consists of two parts; a two inch perforated pipe mounted in the air inlet of the generator and a glass covered cast iron valve box mounted on the side of the generator. Fig. 2 shows the general arrangement of mounting the extinguisher. Steam is obtained for the extinguisher from the mains supplying the auxiliaries, which assures a constant supply, as the auxilliaries are always started prior to and after shutting down the generator.

To avoid the possibility of steam leaking into the generator when the extinguisher is not in use, two valves are used in series joined by a short nipple, the valve nearest the outlet being enclosed in a cast iron box with a glass front, Fig. 1, which must be broken before the steam is admitted to the generator. A small hole is drilled into the nipple between the two valves to indicate any leakage through the first valve.

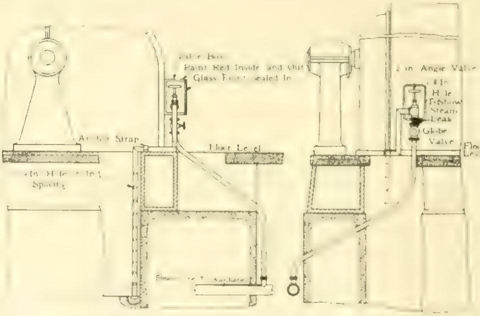

FIG. 2 ARRANGEMENT OF APPARATUS FOR EXTINGUISHING FIRES WITH STEAM

METHOD OF USING EXTINGUISHERS

As the air for ventilation discharges from the top of the generator, smoke or sparks can readily be seen by the turbine attendants, who immediately notify the switchboard operator, by a signaling system, that the generator is in distress. Before admitting steam to the generator it is essential that the generator be disconnected from the bus bars, the field cut out and the damper door closed. This is done manually by the operator, if no breakdown has occurred, and automatically if the windings have grounded or short-circuited, as all generators are protected by the unbalanced relay systems. As soon as the field is cut out the turbine attendant breaks the glass in the valve box and turns the steam on, leaving it on for two minutes. If sparks continue to come from the generator, he repeats the operation until no further indications of fire are seen.

HISTORY OF FIRES

Since the extinguishers have been installed they have been used nine times, with good results, as only in one case was the generator out of service for more than 24 hours. Five fires originated at the support blocks for the end turns; at which point dirt accumulated and fire resulted from static disturbances in the generator.

Two fires originated in the wedges that hold the armature coils in their slots; short-circuits resulted between laminations, which became red hot and, in turn, burned the adjacent fish paper insulation.

One fire resulted from the insulation of the cables underneath the generator breaking down to ground, and one from an armature coil failing and developing into a short-circuit, which destroyed the insulation of the adjacent coils and burnt a large hole in the stator laminations. As the laminations had to be restacked, it was necessary to entirely rewind the generator, since it was not considered good practice to reinsulate and reshape the old coils.

Although the majority of fires have been of a minor nature, it is felt that the use of steam prevented them from becoming disastrous. In the one case, where the armature coil failed and destroyed the stator laminations, the time interval between the failure and the resultant damage was so small that no available known method could have saved the generator, but the prompt use of steam prevented the fire from spreading, thereby, saving the field piece from being roasted. Where the cable leads failed underneath the generator, no damage was done the generator, but in a similar case, previous to the installation of the extinguisher, the flames from the short-circuited cables had damaged the windings sufficiently to necessitate rewinding the armature.

EFFECT OF STEAM CONDENSING ON THE COILS AND LOWERING THE INSULATION VALUE

It has been found from experience that the condensate from the steam evaporates quickly under the influence of the heat of the coils, and only in one case was it necessary, after megger readings were taken, to dry out the winding, which was done by slowly rotating the field for several hours, without current, until the megger readings were high enough to warrant running the unit.

CONCLUSIONS

Steam as an extinguisher for generator fires, is easily adaptable to any power plant. Once installed, no attention need be given to the apparatus, except only to note leaky valves, and renew the glass in the box after a fire. There are no obnoxious odors present due to chemical extinguishers, nor is drying of coils necessary, as after using water. Fires can be brought under control within a very short interval after being noted.

The Fifty Degree Rise Method of Motor Rating

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THE METHOD OF RATING electrical apparatus has passed through a development that parallels very closely the development of the apparatus itself. The great expansion in the use of electric power having occurred within such a short term of years, it is only natural that in the development of apparatus, the earlier types were not thoroughly thought out and perfected, and in some instances two or more different types of apparatus have been developed to perform the same class of work. Perfection of design and elimination of superfluous types have only followed after the results of service and thorough analysis of the best way to meet service conditions have pointed the way.

There has been a similar development in the method of rating motors. In the early days there were no precedents as to rating and motors were built with a view of securing the greatest possible output. At first, they were rated with no temperature rise being given. Then later, arbitrarily, at 40, 50, 55 and 60 degrees C, the safe operating temperatures not having been determined. In the early days, all motors being for direct-current operation, it was found that, in the majority of cases, commutation was the limit of rating and that, with the class of machines that were being built at that time, satisfactory commutation could not be secured at loads that produced temperature rises above about 40 degrees C. The practice of rating motors at 35 or 40 degrees C with a two hour 25 percent overload. came into widespread use. However, other ratings were also used for similar apparatus. A 35 degrees rating with 25 percent continuous overload at 50 degrees rise and 50 percent overload for one hour at 60 degrees rise being one that was widely used. Also 50 and 55 degrees C rise was established and generally used for motors in many classes of service, such as cranes, machine tools, compressors and blowers. With a situation such as this, it was inevitable that a demand should come for simplification and standardization in the basis of rating.

STANDARDIZATION

There were at the time this standardization was carried through, three parties involved. These were as follows:—

a—The A. I. E. E.
b—The Electric Power Club.
c—Users of motors as represented by various associations, for example, the Association of Iron & Steel Electrical Engineers.

A fairly clean cut division of responsibility was established between these parties. The A. I. E. E., an engineering organization, had the duty of establishing the limits of capacity, *i.e.*, they were to study the features involving the life of apparatus; for example, the life of insulating materials when subjected to heat, thereby enabling them to establish the maximum temperature and temperature rise at which it was safe to operate electrical machinery.

The function of the Electric Power Club was to establish commercial ratings for electrical machinery based on the limits of capacity established by the A. I. E. E. The Electric Power Club, being an association of manufacturers who have long been in touch with the requirements of users of electrical apparatus, necessarily took these requirements into account and where any question arose on the part of an association representing the users, committees representing the two conferred.

In addition to the above bodies operating in this country, the International Electrotechnical Commission was recognized as being an interested party and, while the activities of this Commission were interfered with to some extent during the war, progress was made with international standards, and the standards adopted in this country are substantially in agreement with the I. E. C. standards, and additional meetings of the I. E. C. are now being held. This is a very important consideration, since it is recognized that we must take a greater part in the world trade than before, and the provincial and arbitrary bases of rating formerly used in this country have no standing abroad, where 50 degrees C rise is the standard commercial basis of rating generally recognized.

Without going into the history in detail, the result of the A. I. E. E. standardization, so far as it related to the temperature of motors was, briefly: that 105 degrees C ultimate temperature is the safe temperature for the operation of windings insulated with Class "A" insulation, *i.e.* "cotton, silk, paper and similar materials when so treated or impregnated as to increase the thermal limit, or when permanently immersed in oil; also enameled wire." From 105 degrees ultimate temperature is established a temperature rise of 50 degrees measured by thermometer. This is reached by a temperature gradient of 15 degrees having been established as representing the actual difference between the temperature inside and outside of the winding, thus establishing the limiting observable temperature by thermomenter as 90 degrees. A standard air temperature for purpose of rating was then established at 40 degrees, which results in the 50 degree limiting observable temperature rise.

The above results were arrived at by a study of operating conditions with machines operated over a long period of years at known temperature rises and examination of the insulation of these machines; also, a series of laboratory tests on the life of insulation when subjected to various temperatures. The field was covered very thoroughly and there can be no doubt that the conclusions reached represent safe practice.

At the time the work of the A. I. E. E. was completed and adopted the Electric Power Club already had standards of rating for many classes of motors. For the so-called general purpose motor, the standard was 40 degrees C rise with two hour 25 percent overload, when the motor was open; 50 degrees rise for continuous operation, if the motor was semi-enclosed, and 55 degrees rise for continuous operation when the motor was enclosed. Short time rated motors, *i.e.*, for two hour service or less, such as crane motors, machine tool motors, and elevator motors, were rated on the 50 or 55 degree basis.

Again without reviewing the history in detail, the result of the standardization work of the Electric Power Club was the recognition of 50 degrees rise as a basis of rating for general purpose motors, and continuation of the former standard of 40 degrees rise with 25 percent, two hour overload as another basis of rating for these motors, and establishment of 50 degrees rise as standard for semi-enclosed general purpose motors and for open and semi-enclosed short-time rated motors.

PRESENT STATUS

At the present time, motors are being offered commercially for general purpose work on both the old 40 degree rise basis and the new 50 degree basis. It is believed by many that this is a transition period and that the time is not far distant when the single-rated 50 degree motor will be the universal standard. The factors that will bring this result are safety of the insulation at this temperature rise, more economical use of material and simplicity in basis of rating. Assuming, for the purpose of discussion, that this is to be the case, it will be interesting to consider the effect of the 50 degree basis of rating on both design and application.

DESIGN

The use of 50 degrees rise at full load as the single temperature basis of rating permits the designer to make a better distribution of losses in the machine, thereby making the most economical use of materials, a goal that represents one of the great purposes of engineering. In other words, it permits more uniform loading of the materials used. The economies effected by this equal loading of the material not only result in conservation of materials, but become of direct benefit to motor buyers. By comparison, in designing for 40 degrees rise at full load and 55 degrees at 125 percent load, the designer must make concessions in respect to the economical use of materials due to the double basis of rating.

APPLICATION

In applying motors, consideration must be given to several factors that involve the electrical characteristics of the machine, in addition to the temperature rating at full load and rated voltage. These are as follows:—

a.—Momentary Overload Capacity—The momentary overload capacity of the 50 degree motors is the same as that of the 40 degree motor, namely, 50 percent overload momentary in torque, as defined by the rules of the Electric Power Club. So far as this factor goes, therefore, 50 and 40 degree motors may be applied on the same basis.

b.—Starting Torque of Alternating-Current Motors—The starting torque of single and polyphase motors and the "pull-in" torque of single-phase motors is the same for 50 degree motors as for 40 degree motors, as defined by the rules of the Electric Power Club. So far as this element is concerned, there is no difference in the application of 50 and 40 degree motors.

c.—Maximum Running Torque—The pull-out torque of 50 degree motors is the same as for 40 degree motors, as defined by the rules of the Electric Power Club. So far as this factor is concerned, therefore, there also is no difference in the application of 50 and 40 degree motors.

d.—Allowable Variation from Rated Voltage—The rules of the Electric Power Club provide that both 50 and 40 degree motors shall operate successfully at rated load and frequency with a voltage not more than ten percent above or below the name plate rating. Thus, there is no difference in the application in this respect.

e.—Allowable Variation from Rated Frequency—The rules of the Electric Power Club provide that both 50 and 40 degree motors shall operate successfully at rated load and voltage with frequencies not more than five percent above or below the name plate rating.

f.—Allowable Combined Variation of Voltage and Frequency—The rules of the Electric Power Club provide that both 50 and 40 degree motors shall operate successfully at rated load with a combined variation of voltage and frequency of not more than ten percent above or below the name plate rating.

EFFECT OF TEMPERATURE RATING ON APPLICATION

With regard to the effect of the difference in temperature rating on the application, it can readily be seen that it is just as easy to select the correct size of a 50 degree rated motor as it would be to select a suitable 40 degree rated motor. Aside from the redistribution of losses, referred to above, there is no difference between the line of 50 degree motors and the line of 40 degree motors, except that each of the standard horsepower ratings will, in general, be built on a size smaller frame as 50 degree motors than the corresponding 40 degree motors. There are just as many motors available as before, and in order to make an application, so that there will be the same margin of safety, it is only necessary to know as much about the load requirements as was known when applying the 40 degree motor.

There are practically no industrial motor applications where a long period of operation at full load is followed by a two hour period of operation at 25 percent overload. The 25 percent, two hour overload rating given the 40 degree rated motor has become, therefore, solely a means of providing some margin over the actual load requirements. This margin may be desired simply as a factor of safety to insure continuous operation, or to provide for possible increase of load due to increased service requirements, and it is very good practice to allow a reasonable margin. This margin, however, can be provided just as easily with a 50 degree rated motor as with a 40 degree rated motor, and once the proper way of applying 50 degree motors is fully understood, with a greater assurance of safety.

Assume an application requiring a polyphase 1150 r.p.m. motor and with a known continuous load requirement of 19 to 20 horse-power. It is desired to apply a motor that will have a reasonable margin over the present load requirement. A 20 horse-power motor on the 40 degree basis with 25 percent two hour overload is considered, as well as a 25 horse-power motor on the 50 degree basis. The comparison is as follows (based on Electric Power Club guarantees for torques):—

	40 Degree Motor	50 Degree Motor
Horsepower developed at 40 degrees C. rise continuous..	20 horsepower	20.75 horsepower minimum up to 22 horsepower
Horsepower developed at 50 degrees C. rise continuous..	No guarantee	25 horsepower
Horsepower developed at 55 degrees C. for 2 hours.....	25 horsepower	No guarantee
Starting torque, lbs. at 1 ft...	124	154
Momentary overload, running torque, lbs. at 1 ft....	137	171
Pull-out torque, lbs. at 1 ft...	183	229

The weight and cost of these two motors will not be materially different. A study of the above tabulation shows that the 50 degree motor is not only more liberal in temperature rating but it has better torque characteristics than the 40 degree motor. In any given application this 50 degree motor will actually run cooler than the 40 degree motor with which it is being compared, and it will also start heavier loads and have a greater capacity for carrying momentary overloads. The comparison between these two motors shows the typical relation between the 40 and 50 degree motor. Selecting the standard ratings of 20 and 25 horse-power makes it easier to see at a glance the relative characteristics of the two as the step between the two is just 25 percent; fundamentally, however, similar relations hold throughout an entire line of motors. In most cases, where the load conditions are known, a 20 hp. 50 degree motor can be applied to do the same work as formerly done by a 20 hp. 40 degree motor at a saving in cost and weight, but where it is desirable to provide considerable margin, the plan outlined above can be followed without sacrifice.

CONCLUSION

In view of the extensive tests made to determine the safety of 50 degrees rise as a basis of rating, the large number of motors now operating at that temperature, and the way in which the motors are designed to take care of possible variations in voltage and frequency, it is clear that there is no reason for apprehension as to such motors having a satisfactory life of insulation. It is also clear that, if all motors can be brought to this common basis of rating, the application of motors in the future will be a simple matter and the applications will be better balanced than at present with respect to all of the needed characteristics.

Use of Electricity in Metallurgical Processes

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THE DEVELOPMENT of electrometallurgical processes to a position of great industrial importance during the last decade was one of the noteworthy steps in the progress of metallurgy. This development has been of utmost importance to the central station, as most electrometallurgical plants, especially electric furnace processes, use power from the central station. In 1910 there were electrometallurgical or electrochemical power loads in about 25 cities in the United States and Canada, but today such loads are found in over 200 cities. Ten years ago so little was known of the characteristics of the electric furnace load, that few power companies cared to have them on their lines. Today, with an electric steel furnace in practically every manufacturing city in the country, the load is considered a desirable one. The wide extension to so many communities is, of course, due mainly to installations of electric steel furnaces during the war. Although the number of steel furnaces installed was far greater than could have been foreseen ten years ago, and although many were installed mainly for war purposes, it does not appear that there has been an over-development in this respect. The quality of electric steel has become so established that the process is here to stay, and will probably supersede other processes for the production of castings, and super-refining will be widely used in the Bessemer and open hearth steel manufacture.

Disregarding electrochemical processes, electricity is used in the metallurgy of the following metals, either as a heating agent or for its electrolytic effect:—pig iron, steel, cast iron, the ferro-alloys, aluminum, copper, brass, lead, zinc, gold and silver. Table I gives data regarding the quantity of power used in these processes in the United States and Canada as closely as can be estimated from information available. There is a total load of approximately 1 300 000 kv-a used in electrometallurgical processes in the United States and Canada, not including motor load.

TABLE I—INSTALLED POWER CAPACITY IN ELECTROMETALLURGICAL PROCESSES IN THE UNITED STATES AND CANADA

Process	Kv-a Load	Process	Kv-a Load
Pig Iron	none	Brass	23 000
Steel	600 000	Lead	1 400
Ferro-alloys	200 000	Zinc	60 000
Aluminum	350 000		
Copper	15 000	Gold and Silver	1000

PIG IRON

Although the electric smelting of iron ore was developed simultaneously in the United States and Sweden, and although in 1908 Dorsey A. Lyon erected at Heroult, California the first electric furnace to produce pig iron commercially, the process is no longer in operation in this country. Pig iron is being produced in the United States by electric melting of scrap, but not smelting iron ore. The plant at Heroult was increased to 5000 kilowatts capacity, but in 1914 production of pig iron was discontinued and the plant operated on ferro-alloys.

On the other hand, development in Sweden and some other countries has been steady. The furnace developed is similar to the shaft furnace installed by Lyon in 1908, which is especially adapted for production of low carbon and silicon iron, and not foundry iron. It operates best with charcoal as a reducing agent, and in fact proved a failure at Hardanger, Norway, in 1912 when operating with coke. At Notodden, Norway, a furnace of the pit type has been developed, which operates satisfactorily with coke and also produces foundry iron. The last two furnaces operated at Heroult, California, were also of the low pit type, and could be operated with coke and charcoal mixed for production of foundry iron.

Electric furnaces for smelting of iron ore are now installed as shown in Table II. In 1910 there were two furnaces of a total power input of 3500 kilowatts.

TABLE II—ELECTRIC FURNACES SMELTING IRON ORE

Country	Type of Furnace	Number of Furnaces	Size of Units Kv-a	Transformer Capacity Kv-a
Sweden	Shaft	10	2000 to 7000	64 000
Norway	Pit	3	1200	3600
Norway	Shaft	1	3000	3000
Switzerland	Shaft	2	3000	6000
Japan	Shaft	2	3000	6000
Italy	Shaft	6	3000	18 000

At the present time there are installed thirty-three electric pig iron furnaces of from 2000 to 7000 kv-a, a total load of 100 600 kv-a, having a production capacity of 250 000 tons of pig iron per year. During the war, production costs have favored electric smelting, so that electric pig iron is now being produced in Sweden for five dollars per ton less than blast furnace charcoal iron. This is in spite of an average increase in power cost of from eight to twelve dollars per horse-power-year.

The electric iron smelting furnace produces pig iron with a power consumption of from 2000 to 3000 kw-hrs. per ton of pig iron, the lower figure being for white iron and the higher for grey iron. The electrode consumption varies from 13 to 20 lb. per ton of pig iron. As the furnace operates with the arc buried in molten slag, the electrical load is very steady, with few fluctuations except while tapping. In a plant designed for efficient handling of electrodes, it should be possible to attain an average load factor of 80 percent.

The Swedish furnaces use three-phase, 25 or 60 cycle power, with a secondary transformer range of 50 to 100 volts, but usually operate at 80 volts. The furnace has six electrodes, with one of the three transformers to a pair of electrodes. The high-tension side is connected in delta. The load on the furnace is not regulated by raising or lowering the electrode, as on ferro-alloy furnaces, but by voltage control on the primary. On 25 cycles, the power-factor is 95 percent, but on 60 cycle current it may be as low as 80 percent.

Electric furnace production of pig iron will hardly develop to any great extent in the United States along the line of development in Sweden, because of the cost of power, but the writer believes that the time is coming, particularly in the western states, when pig iron, more specifically cast iron, will be made by melting of scrap iron, scrap steel, iron ore, coke and lime in the electric furnace to produce iron for direct castings or for pig iron. During the war, a considerable quantity of low phosphorus pig iron was made in Canada and the United States by electric melting of steel scrap. The production late in 1918 was 4000 tons per month. Six plants were in operation in Canada and two in the United States. While it is not probable that these plants are operating today, there seems to be a future for the process, especially in foundries where the cost of pig iron is high due to freight. The writer knows of one city where the foundries pay $50 per ton for pig iron laid down at their plants. Iron in the ladle could be made by the electric process for $35 per ton.

The metallurgy of synthetic electric furnace cast iron was worked out on a large scale by C. A. Keller* in France during the war. Three plants were erected with a total power input available of 40 000 kv-a. During the war 150 000 tons of castings were made with metal cast direct from these electric furnaces, of which there were 16 of from 1000 to 2200 kv-a size. The power consumption was from 675 to 800 kw-hrs. per ton of cast iron, with an electrode consumption of 15 to 20 lb. per ton of cast iron. Any grade of iron desired can be produced. All of the furnaces were of the single-phase type with two electrodes in series. The process was conducted as a continuous operation, the furnace being kept full of charge. With large units, the load is very steady, but it is probable that in the operation of small 500 kilowatt units there might be momentary overloads. These would be no worse than in a steel melting furnace. The power-factor of the Keller single-phase furnace is about 80 percent on 60 cycles. The furnace is operated at 50 to 70 volts.

Another use of the electric furnace is in refining gray iron from the cupola. Cupola iron, after treatment in the basic electric furnace, shows a marked decrease in sulphur and increase of transverse strength. At present the process appears adaptable only for the very highest grade of castings. The electric furnace is also being used in production of malleable iron castings, and has been considered as a mixer for keeping molten blast furnace pig iron hot before casting into pipe.

STEEL

The most marked increase in the use of electricity in metallurgical processes during the past decade has been in the electric furnace production of steel. In 1904 there were four small electric steel furnaces in operation in Europe. In 1910 there were sixty-seven furnaces in operation, eleven not working, and thirty-six in course of construction throughout the world. Of this total of 114 furnaces, seven were installed in the United States and Canada with a total power input of 5600 kv-a and a charge capacity of 40 tons per heat.

On January 1, 1920*, there were installed or under construction in the United States and Canada 363 furnaces with a total charge capacity per heat of about 1600 tons and a power input of about 600 000 kv-a. Of the 363 furnaces, 323 were installed in the United States and 40 in Canada. The number of electric steel furnaces in the world is estimated at 875.

The production of electric furnace steel in the United States in 1917 was 304 543 gross tons. Probably 1918 and 1919 will show a production of over 400 000 gross tons for each year. Almost 50 percent of the 1917 production was alloy steel. Of the 323 furnaces in the United States, 54.5 percent are being used for making castings.

The most marked development of the electric steel furnace has been in the production of ingot alloy steels for automobile construction and high speed steel. The electric furnace operating with a basic lining produces tons of high grade alloy steels per heat as compared with the crucible furnace producing pounds. Lower grade raw materials can be used, because of the refining to remove phosphorus and sulphur which can be readily performed in the electric furnace. The electric furnace has proven particularly successful in the production of alloy ingots, such as chrome-vanadium steel, turning out a product better in quality than similar open hearth steel with a much lower loss of alloys by oxidation. For the production of high-speed steel in large heats the electric furnace proved well adapted during the war, it being common practice to pour five ton heats of steel valued at three to five dollars per pound. However, the substitution of the electric furnace for the crucible furnace will be very gradual, because it is not yet demonstrated that average electric high-speed steel is quite equal in quality to the highest grades of crucible high-speed steel. To meet the grade of the highest quality crucible steels, the electric furnace product must be made from the most pure raw materials available, and even then, considering electric steel versus crucible steel from condition existing in each case, it does not seem possible that melting conditions can be as closely controlled in the electric furnace as in the crucible.

A future probable large development, in electric steel, is the use of the furnace for finishing molten converter and open hearth steel. The Illinois Steel Company has installed ten 30 ton electric furnaces to treat steel which has been first blown in the Bessemer converter, then held in the open hearth, for eventual transference to the electric furnace. This process was used to

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Trans-American Electrochemical Society, 1920, C. A. Keller.

*C. F. Cone, *The Iron Age*, Jan. 1, 1920.

a small extent in the early days of electric furnace steel production in this country, and a few years will probably see its general adoption.

From the viewpoint of the central station the most important phase of electric steel development is in the electric furnace production of steel castings. Except for manufacturers of high-speed steel, most companies producing alloy steels generate their own power and do not buy from the central station. This is especially true in large plants using the duplex process for refining molten steel. On the other hand, practically all foundries buy their power. Electric steel castings can now be made much cheaper than converter castings, and at as low a cost as open hearth castings. The grade of the castings is better than the product of either of the other methods.

A great advantage of the electric furnace over the open hearth is the rapidity with which heats are made, so that it does not require handling of large quantities of metal as in the case of the open hearth. Within a few years the electric furnace will probably replace all other processes for making steel castings, and most castings will be produced without refining, by melting scrap on an acid bottom.

As a central station load, the electric steel furnace gives the least desirable load of any of the uses of electricity mentioned in this paper. This fact does not make it an undesirable load, however. In fact, it is a very desirable load, although its load factor is low compared with that obtained in some other electrometallurgical processes. This is because most foundries operate on a ten hour day instead of a twenty-four hour day. On a ten hour day operation, a load factor of 18 to 30 percent is obtained. On a twenty-four hour day the load factor will vary from 40 to 55 percent when making castings. This low load factor, as compared with other electrometallurgical industries, is caused by time lost in charging and pouring when the power is off. Due to greater length of time between pouring, a furnace producing ingots on a basic bottom with refining should have a higher load factor than those mentioned, but this is offset by the present common practice of running with about half or one-third load during the refining period at the end of a heat. A furnace refining molten steel instead of melting cold scrap should attain a load factor of 75 percent on twenty-four hour operation.

The power consumption varies from 550 kw-hrs. per ton when melting scrap on an acid bottom for castings, to 800 kw-hrs. per ton when making alloy steel ingots requiring refining. The voltage on the only type of single-phase furnace now used is about 140 volts on the arc, 220 volts open circuit. On two and three-phase furnaces, the voltage is from 90 to 110 volts. The power-factor of the single-phase furnace mentioned varies from 50 to 70 percent. The two and three-phase furnaces have power-factors of from 85 to 95 percent. The electrode consumption is 15 to 25 pounds per ton of steel.

During recent years, the tendency in electric steel furnace construction has been to increase the power input per ton; to use three-phase current and automatic regulators; not to have large reactances in the primary circuit; and not to build furnaces with a bottom electrical connection, at least a connection carrying all of the load. In fact, now that the basic Heroult patents have expired, most new types of furnaces appear to be the original Heroult furnace embellished and camouflaged. The power input per ton of charge has been increased from 170 kw in the early furnaces to 500 kw in the most recent steel casting furnaces. One furnace has been built with electrical connections so that the secondary voltage may be reduced one-half during refining. The use of three-phase current has become almost standard, either as three-phase current in the furnace or three-phase converted to two-phase. Few single-phase furnaces are being built. The single-phase furnace with a bottom contact, however, blazed the way for rapid melting of scrap for steel castings on an acid bottom.

The use of heavy reactance in the circuit is being discarded, and furnaces are generally operated with a moderate reactance and automatic regulators. Common reactances are 7 to 15 percent in the transformer. The bottom contact, as used for carrying all of the current, has apparently gone out of use with the abandonment of single-phase furnaces, although it is still used for putting a small part of the current through the bottoms of some two-phase and three-phase furnaces.

The central station can better the load factor of the electric foundry furnace by making it an object for the customer to operate his furnace 24 hours per day, through the decreased cost per kw-hr. he obtains. Of course, this depends on the peaks in the power company's industrial and lighting load, but there is at present a tendency to install small furnaces for 24 hour operation rather than large furnaces for ten hour operation, and it is to the advantage of both parties that this tendency be encouraged. The furnace with a moderately high power-factor, 85 percent, has proven to be a better load than the furnace with a very high power-factor, 95 percent, because it is not so sensitive to short-circuits in the furnace, and at the same time there is enough reactance present to render electrode regulation easy with regulators. The use of furnaces with heavy reactances and hand regulation of electrodes should be discouraged, as the heavy reactance is not necessary, if regulators are installed.

Electric furnaces of the carbon resistance type have been installed in considerable number for the heat treatment of forgings and castings. The furnaces are ingeniously designed with a very complete automatic control of temperature, and control movement through the furnace of the piece being treated. The heating element is a resistor of granular carbon confined in carborundum fire sand troughs, which results in a uniform load without surges, and a power-factor of 98 percent or better. The load on the furnace is controlled by variation of secondary voltage with taps on the secondary of a special type of transformer. The electric heat treatment of steel is certain to become common practice even at a higher cost because of the ease of control and uniformity of the results obtained. Single-phase furnaces of 900 kilowatts power input have been installed alone, or with two or three connected in balance on a three-phase circuit and operated successfully. A further advance is the adaptation of this type of electric furnace to the soaking pit for large steel ingots and billet reheating furnaces.

Another type of electric heating treating furnace was developed during the war, in which the heating unit consists of a calorite ribbon mounted on a cast iron supporting plate and insulated therefrom by suitable refractory material. The furnaces are of the cylindrical, vertical type and take three-phase, 440 volt current. Units of 400 kilowatts capacity have been built. The current is automatically thrown off and on as the temperature rises above or falls below the desired point. These furnaces were designed for the heat treating of gun barrels, but can readily be adapted for the industrial uses of the future.

FERRO-ALLOYS

The war demand brought the electric furnace ferro-alloy capacity to a point which, with the arrival of a more normal peace demand for ferro-alloys, puts the industry in much the same condition as existed in the European calcium carbide industry in 1899, when over-production and patent litigation compelled most plants to look for new products, which strangely proved to be ferro-alloys. The increase in installed furnace transformer capacity for ferro-alloys production was enormous from 1915 to 1918. In 1910 there were only two plants in the United States and Canada which produced ferro-alloys in the electric furnace. They had a total transformer capacity of possibly 20 000 kv-a. On January 1, 1920, there were forty plants with a combined transformer capacity of 200 000 kv-a. At the date of writing, probably 75 percent of these plants are not operating. Many of them are in the hands of a receiver and will eventually be dismantled. Probably not over half a dozen of the plants erected during the war, for war purposes, paid back their plant investment before the armistice. Companies which were organized with sufficient operating capital will doubtless, with proper management, return the investment in time. It will be slow, because the market has been dead for all alloys, except ferrovanadium, until two months ago, when the price of ferromanganese began to advance from as low as $100 per ton until now it has reached the war price of $250 per ton. This is due to failure of imports of ore. Between the buyers and the government war minerals policy, the domestic ore producers got such a shaking down after the armistice that it will be a long time before there will be any quantity of domestic ore produced, except by ferromanganese manufacturers operating their own mining properties.

With the enormous increase in plant capacity, the United States easily led the world in production of ferro-alloys when the armistice was signed. The plant capacity of ferrosilicon had increased from 10 000 or 15 000 tons per year to 100 000 tons per year. Instead of importing ferrotungsten and ferrochrome, large quantities were exported. Ferrovanadium, which had always been exported, was shipped abroad in larger quantities than ever. But the two most important developments have been the electric smelting of manganese ores and the increased use of molybdenum in steel.

In 1914 there were no electric smelting plants built mainly for production of ferromanganese. Two plants at Niagara Falls made it electrically at irregular intervals, presumably to keep their furnaces in operation when the market for other alloys was dull. On Armistice Day there were ten plants of total transformer capacity of 55 000 kv-a, and production capacity of about 80 000 tons per year. At the close of 1918 about 15 percent of the ferromanganese production of the United States was being made in electric furnaces. With two exceptions these plants are now out of operation, the two largest having resumed work when the price of ferromanganese advanced several months ago.

Through the interest of one of the largest smelting companies in the world in a Colorado molybdenite deposit, which is probably the most extensive known deposit of molybdenite, large scale investigation of the use of molybdenum in steel has resulted. This work shows that the addition of small quantities of molybdenum to chrome, nickel, chromenickel or chrome-vanadium steel, results in a steel of greater strength and toughness, which is easily forged, easily heat treated and easily machined. Probably 300 tons of ferromolybdenum were produced in 1918 as compared with less than 25 tons in previous years. There was a very small production in 1919. Some electrical characteristics of electric ferro-alloy furnaces are given in Table III.

TABLE III—ELECTRIC FERRO-ALLOY FURNACES

Product	Size of Furnace Kv-a	Phases Usual Type	Secondary Phase Voltage	Percent Power Factor	Percent Load Factor	Percent Overload Swing	Load Curve
Ferrosilicon	750 to	1	80	92	80-85	[illegible]	Smooth
Ferrosilicon	7500	3	120	75	80-85	15	Smooth
Ferromanganese	1200 to	3	65-75	85	80-85	10	Very Smooth
Ferromanganese	5630	3	115-120	70	80-85	10	Very Smooth
Ferrochromium	1000 to	3	65-75	95-90	80-85	25	Smooth
Ferrochromium	1500	3	75	85-90	80-85	25	Smooth
Ferrotungsten	75 to 250	1 to 3	55-75	90	50-70	50	Irregular
Ferromolbdenum	75 to 250	1	55-75	90	50-70	50	Irregular
Ferrovanadium	50 to [illegible]	1	55-75	90	70-80	25	Smooth
Ferro-uranium	75 to 150	1	55-75	[illegible]	70-80	50-100	Very Irregular
Ferrotitanium	[illegible]	1	55	[illegible]	[illegible]	50	Irregular

Practically all ferrosilicon furnaces are now installed in three-phase units. If it is desirable to install units of less than 1500 kv-a capacity, a single-phase furnace with two vertical electrodes in series is usually built. There is at least one plant in this country equipped with single-phase furnaces of this type. The ferromanganese furnace gives about the smoothest and most easily controlled load of any of the ferro-alloy furnaces.

Ferrochrome is made in both single-phase furnaces and three-phase furnaces. Before the war some engineers from the largest point of ferro-alloy production, Niagara Falls, claimed that ferro-chrome could not be made in a furnace of over 1000 kw capacity. This was proven to be a fallacy by the recent installation of a 1500 kw furnace in Denver which operates more satisfactorily than a smaller furnace at the same point.

Ferrotungsten is almost universally made in the single-phase furnace of the Siemens type with the bottom forming one electrode. The metal is allowed to build up in the furnace and the furnace torn down to remove it. This results in a considerably more irregular load curve than with the larger tapping furnaces. One plant, now dismantled, successfully made ferrotungsten in a three-phase furnace.

The characteristics of ferromolybdenum operation are much the same as for ferrotungsten, except that when the 55 percent molybdenum alloy is being made, it can be produced in a tapping furnace instead of a knockdown furnace. Electric furnace ferrovanadium is usually produced in a single-phase furnace, either of the Siemens type or series type. Ferro-uranium is made in small furnaces of the Siemens type. Due to absence of slag in the operation, the load is very irregular, and considerable reactance is usually used in the circuit, especially if automatic regulators are not used. The load characteristics of a ferrotitanium furnace are somewhat similar to those of ferro-uranium.

In commercial production of these ferro-alloys, ferrosilicon, ferromanganese and ferrochromium can be made in three-phase furnaces as readily as in single-phase furnaces, and there is no reason for permitting installation of single-phase furnaces for their production. Ferrotungsten, ferro-molybdenum, ferrovanadium, ferro-uranium and ferrotitanium must be made in single-phase furnaces. At least the operation is much more apt to succeed in a business way. For this reason, a power company should not object to installation of single-phase furnaces by a company desiring to make these alloys. It may be noted that the line of division in these alloys is between metals of a low melting point and metals of a high melting point. Silicon, manganese, and chromium have comparatively low melting points when electric furnace temperatures are considered, while the melting point of tungsten, molybdenum, vanadium, uranium and titanium is high.

There appears to be no reason for the installation of heavy external reactances for the production of any ferro-alloys, except possibly ferrotitanium and ferro-uranium. For these alloys, either regulators or reactances are probably necessary. In the operation of plants without regulators and with regulators, on the same ferro-alloys, in the same size furnaces, no marked difference in the straightness of the load curve is noticeable. The regulator saves the time of one man on three furnaces or three electrodes when hand control is used. A good man will get as good a load curve as a good automatic regulator but, of course, the regulator eliminates the human element.

Recently the writer put in operation a ferro-alloy plant with the understanding that the primary circuit was 4500 volts. Furnace transformers were installed with a ratio of 4500/75. During the twenty-four hours, the secondary furnace voltage varied from 72 to 85 volts, depending on whether the industrial load of the town was on or off. This results in two things—it ran up the demand charge because the furnace would run at the same amperage with higher voltage unless watched continuously, and means the production of a poorer grade of metal when running a knockdown furnace, as the button will not be so compact with high voltage. The difficulty was not caused by anything in the furnace transformer, which had a reactance of seven percent, as the same ratio of variation was shown on the 110 volt lighting circuit. In another case a large furnace was installed on a power line which the power company claimed was more than heavy enough. It resulted in a line drop of 25 percent, which made the furnace voltage so low that enough power could not be gotten into the furnace to keep it hot. Ferro-alloy furnaces are run on certain voltages because practice has proven these voltages to be the best. Of course, in 3000 to 4000 kilowatt furnaces it is sometimes necessary to raise the voltage above the desired limit for good metallurgical practice, in order to get power into the furnace.

The electric smelting load, at the present time exemplified by ferro-alloy furnaces, is probably one of the best loads a power company can get, and in the future may prove a much larger load with application of electricity to smelting of non-ferrous ores.

ALUMINUM

Since the separate discoveries by Hall and Heroult in 1886, that aluminum could be produced by electrolysis of alumina with a fluride electrolyte, the yearly production of aluminum has increased to a world output of 489 000 000 pounds* in 1918. Aluminum is now fourth in quantity production of non-ferrous metals, being surpassed only by copper, zinc and lead in the order named. It will probably pass lead and zinc within twenty years. In variety of uses it is only surpassed by iron and copper. All aluminum is produced in a direct-current, electrolytic cell with a molten electrolyte, usually heated by the passage of the current. The world output of 1918 required about 700 000 kv-a, and the estimated installed power capacity being used for aluminum in the United States at the present time is 350 000 kv-a. The production of the United States in 1918 was 225 000 000 pounds. France was the next largest producer with a production of 48 400 000 pounds. In 1910 the production of the United States was only 12 000 000 pounds and the installed power capacity about 75 000 kv-a.

*J. W. Richards, *The Mineral Industry*, 1918.

The practical metallurgy of aluminum, as practiced in the United States, has been kept as secret as possible. In one of the most recently constructed plants the furnaces or cells take 20 000 amperes of direct current at seven volts. Seventy of these furnaces are connected in series on a 500 volt, direct-current line. Power is supplied to the battery by a 10 000 kilowatt, direct-current generator direct driven by a water wheel. In most European plants, the direct connection of the water wheel to the direct-current generator has been common practice, because the aluminum plants were generally built at the power site. This practice has not been common in this country because the power source has usually been the high-tension line of a central station. The power consumption is about 15 kw-hrs. per pound of aluminum. The load is ideal for a central station.

In addition to the use of electricity in the production of aluminum, it is also used for melting aluminum in furnaces of the resistance type. A carbon resistor furnace of 500 kw capacity has been put on the market for this purpose.

COPPER

Since 1883, electricity has been used in this country to refine copper. There are nine electrolytic copper refineries in the United States. Direct current is supplied from motor-generator sets or converters. In electrolytic copper refining, pure copper is produced from blister copper, by suspending the blister copper as an anode in a solution of $CuSO_4$ acidulated with H_2SO_4, the current depositing pure copper on a copper cathode, the impurities forming an anode mud. The electrolytic copper refining capacity of the United States is 1 394 000 tons per year, requiring about 45 000 kv-a. Power is generally supplied at 145 to 220 volts, and the cells are usually connected in multiple. The greater part of the electrolytic copper refining capacity of the United States is located on New York harbor, and power is generated by steam in the power plant of the refinery. Seven to eleven pounds of copper are deposited per kw-hr.

The electrolytic deposition of copper from leaching plant solution is in practice on a large scale at Ajo, Arizona. The power installation is 15 000 kv-a, of which only one-half is required to operate the plant. As high as 2.5 pounds of copper have been deposited per kw-hr.

An increasing quantity of electricity is being consumed in the large copper smelting plants for removing dust from smelter smoke. A new Cottrell smoke treatment plant has been completed at Anaconda, which uses approximately 1000 kw. This use of power will be increasing until almost every smelting plant is equipped. The process is also being used on manganese furnaces and lead furnaces.

There has been a remarkable growth of the use of the electric furnace for melting brass and non-ferrous metals. From one silver melting furnace of the carbon resistor type in 1914, the number had grown to 261* on March 1, 1920. Of these furnaces, 61 are carbon resistor furnaces, 118 are induction furnaces, and 82 are arc furnaces of various types. Furnaces are being used to melt brass castings, wrought brass, bronze, copper and nickel. The total estimated installed transformer capacity is 23 000 kv-a, of which one-third is for carbon resistor furnaces, one-half for arc furnaces, and the balance for induction furnaces. The carbon resistor furnaces operate at 98 percent power-factor, giving a very steady load. The most common size has 105 kv-a transformer capacity. The induction furnaces are built in the smallest units of any of these furnaces, taking 30 to 60 kw load with a power-factor of 70 to 85 percent. The indirect rotating arc furnace operates at 80 to 90 percent power-factor, and is built in sizes up to 300 kv-a. Depending on the kind of brass being melted, the power consumption varies from 250 to 400 kw-hrs. per ton.

The electric brass furnace is rapidly becoming an important load for the central station. Except for the single-phase feature it makes a good load for a power company. It is built in such small units that the fact it is single-phase should not prove seriously objectionable.

LEAD

Electricity is used for the refining of lead bullion by the Betts process at Trail, British Columbia, East Chicago, Indiana, Omaha, Nebraska, and New Castle on Tyne, England. The general layout of a plant is similar to that of an electrolytic copper refinery. Cast anodes of lead bullion and lead cathodes of electrolytic lead connected in multiple are suspended from copper bars across a rectangular tank in which there is an electrolyte containing lead fluosilicate and free hydrofluosilic acid. The current enters the anode, passes through the electrolyte to the cathode, dissolves lead from the anode and deposits it on the cathode. The impurities form anode mud or slime, which is refined to recover metals of value. The electrolytic lead refining capacity of the United States and Canada is about 90 000 tons of lead per year. The installed power capacity is about 1400 kv-a. Fifteen pounds of lead are deposited per kw-hr. Power is generally supplied at 90 to 115 volts, and the cells connected in various arrangements.

ZINC

The commercial application of electrolytic precipitation of zinc from sulphate solution in the hydrometallurgy of zinc is less than five years old. The first recorded production in the United States was 10 963 tons in 1916, which in 1918 had increased to 38 885 tons. The electrolytic zinc production of 1918 was 7.3 percent of the total production of the United States. At the present time there are four commercial plants for production of electrolytic zinc in the United States and one in Canada, with a total production capacity of about 300

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*E. F. Cone, *The Iron Age*, Mar. 4, 1920, p. 655.

tons of zinc per day. One plant has been built in Australia and two in Tasmania.

The secret of successful electrolytic precipitation is to precipitate the zinc from a pure electrolyte. Sheet lead anodes and sheet aluminum cathodes are used. The zinc is stripped from the aluminum cathode and melted for casting into ingots. The power consumption in one plant is as low as 1.7 kw-hrs. per pound of zinc precipitated. In others it is as high as 2.5 kw-hrs. per pound of zinc. In one plant three-phase current is delivered at 44 000 volts, transformed to 2300 volts, and converted to 250 volt direct current by synchronous motor-generator sets. Sixty cells are connected in series, with the voltage per cell 3.5 volts. The installed transformer capacity of electrolytic zinc plants in the United States and Canada is about 60 000 kv-a.

A large 1000 kw melting furnace of the carbon resistor type was put in operation in 1919 for melting the zinc cathode of an electrolytic zinc plant. In the first weeks of operation the furnace melted zinc with a power consumption of 70 to 80 kw-hrs. per ton of metal charged and a metal loss in dross of 0.024 percent.

Although there has been considerable experimenting in the United States and Canada during the past ten years on electric smelting of zinc ores, nothing has been done in commercial production. Electric smelting of zinc ore and dross has been practiced commercially in Sweden since 1901. Two plants are in operation in that country of a total transformer capacity of 15 000 kv-a. A large part of this capacity has been used for smelting dross. When smelting ore the main difficulty has been in production of blue powder instead of zinc. Single-phase furnaces of 350 to 750 kv-a size are used. Although the blue powder difficulty appeared practically solved by experimenters in the United States several years ago, nothing commercial has resulted.

The use of electricity in metallurgical processes for treatment of ores is certain to increase slowly. The operation of the Anaconda plant has shown that zinc can be produced electrolytically at a profit with zinc at its normal price. Electrolytic plants will probably prove most successful in large units, and the growth will be toward a few large installations rather than a few small ones. All of the plants erected to date use central station power. These plants give an excellent load of high load factor and high power-factor.

GOLD AND SILVER

Electrolytic refining of gold and silver bullion has been practiced for a number of years in the United States mints at Philadelphia, Denver and San Francisco, and the New York assay office. It is also used in the refinery of one Perth Amboy smelting plant. In silver refining, an electrolyte of silver nitrate solution is used. In gold refining the electrolyte is a trichloride solution of gold. The power involved in these installations does not exceed 500 kilowatts.

Several electric melting furnaces were installed in United States mints during the war, which proved successful for melting silver dollars, nickel and copper.

FUTURE DEVELOPMENT

Increased load of central stations from metallurgical processes depends on several factors: *1*—cost of power; *2*—location and freight rates; *3*—the price of coal and oil now used as fuels in metallurgical processes; *4*—industrial demand for the highest grade metals and alloys. In melting steel and non-ferrous metals and electrolytic refining of metals, a power cost of one cent per kw-hr. is reasonable, but a smelting process or electrolytic reduction process, except when producing the higher priced ferro-alloys, such as ferrovanadium, cannot stand this price. The smelting furnace operator does not expect the two mill power of Sweden, but in most cases he must have five mill power. The cost of power limits the following electrometallurgical processes to hydroelectric power: smelting of iron ore, ferro-alloy production, aluminum, electrolytic zinc precipitation, and electric smelting of non-ferrous ores.

Location and freight rates will have a considerable influence on the substitution of electrical processes for combustion methods. Western foundries will probably be making iron castings by electric melting of scrap iron and steel, or by smelting a mixture of scrap and iron ore instead of by melting pig iron shipped from the east with a $12 to $18 freight rate added to the eastern market price, once somebody has demonstrated the saving possible. Many large western smelters have ceased operation because of high costs and shortage of ore. This may result in installations of electric furnaces for treatment of high grade ores and flotation concentrate.

The price of coal and oil has reached such a point in many western smelting centers, where hydro-electric power is available, that if electric furnaces were developed to a point where they could be substituted for combustion furnaces, substitution of electric furnaces would undoubtedly result. This development is certain to come before many years, if fuel prices remain high, particularly oil.

Modern industry demands high grade products. Even if electric furnace steel costs slightly more than open hearth steel, the requirement of the best steel possible for present day industrial purposes is certain to result in a large increase in the production of electric furnace steels and non-ferrous alloys. This will eventually increase the consumption of electrically produced ferro-alloys.

In summary, a considerable increase of the uses of electricity is to be expected in the following processes:

1—Iron castings from scrap or a duplex process of cupola melting with electric furnace refining.

2—Steel castings and alloy steels.

3—Ferro-alloys.

4—Aluminum.

5—Brass melting.

6—Electrolytic zinc.

7—Electric smelting of non-ferrous ores.

Steel Clad Distribution Transformers

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Transformer Engineer,
Westinghouse Electric & Mfg. Company

THE DEMAND for distribution transformers at the present time, far exceeds the supply. This is due to many immediate causes, the most of which can be traced back to the world war. Among the most obvious of these reasons are,—

a—Depletion of the central station's stock of lighting transformers.

b—The extensive home building and house wiring program upon which the country is entering.

c—Increased use of electrical apparatus in the home.

It seems probable, at least in the absence of a general financial disturbance, that the present demand will be maintained for some time.

Under existing manufacturing conditions, it is difficult to maintain the proper supply of castings required by the various industries. One of the greatest factors in this condition is the labor situation, men generally preferring the lighter and cleaner work in other lines to that of moulding. From the viewpoint of ease of fabrication, the manufacturer is in a better position by substituting sheet metal for cast iron, and contributes a benefit to the industry by lessening the demand for castings. While quantity production is benefitted, the cost is not materially reduced. This is because the fabricated parts require expensive tools, with heavy up-keep charges. A distinct advantage, however, is secured, as fewer men are required as compared to the hand work involved in making castings.

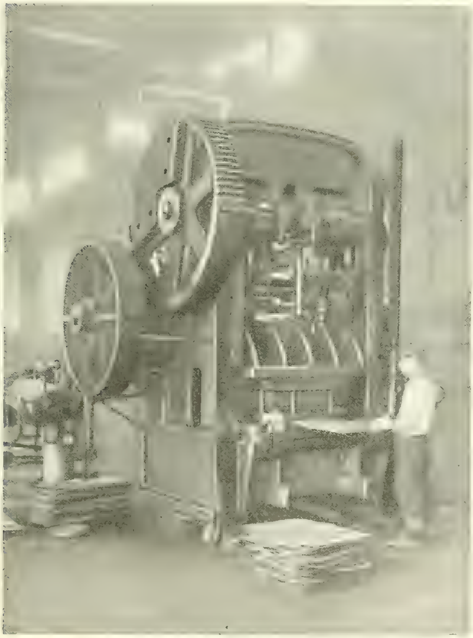


FIG. I—BLANKING MACHINE WHICH IS USED IN THE MANUFACTURE OF COVERS, TANK RIMS AND CASES

WEIGHTS AND DIMENSIONS

In the development of the steel clad transformers described herein, the suggestions and criticisms of operating engineers have been among the main influences shaping the design. A large number of these suggestions have indicated the desirability of reduction of the weights and outline dimensions of transformers, as the weights determine largely the ease with which distributing transformers can be shipped, handled and installed. Further, since they are usually mounted on poles, heavy transformers are objectionable, not only because of the difficulty raising them into position, but also because of the strains upon poles and cross-arms.

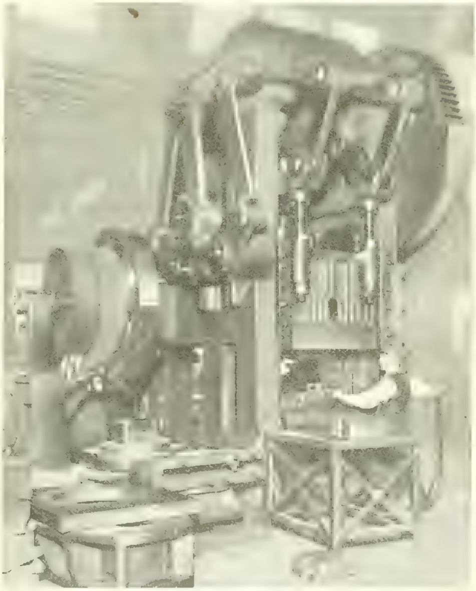


FIG. 2—COMPOUND DRAWING PRESS WHICH FORMS THE COVERS AND TANK RIMS FOR THE TANKS

A reduction in the volume of the transformers gives greater ease of handling and storing. The mounting distance from the center of the pole is also a matter of importance, from the point of view of the strain on the pole and cross-arms.

The desirability of a reduction in the weight and dimensions of the transformers, in addition to the question of quantity production, further emphasized the desirability of the use of sheet metal parts. The development of the steel clad transformer has permitted a reduction of the average bending moment on the pole to approximately 60 percent; of the weight to 66 percent; and of the amount of oil required to fill the transformer to 60 percent of the corresponding quantities for the design with cast-iron parts.

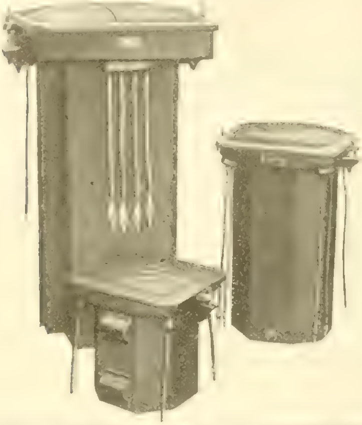


FIG. 3—GROUP OF 5, 15 AND 50 KV-A TRANSFORMERS

MANUFACTURE

The material used for the manufacture of these cases, covers and end frames is a grade of sheet metal adapted to the conditions of manufacture and service. It can be cold drawn, and welded with the acetylene flame and, in addition, due to its chemical purity, is inherently rust resisting. It is received from the mills in sheets of about 4 by 7.5 feet. Three thicknesses of sheet are used; namely, 0.078, 0.109 and 0.125 inches, the thinner material being used on the smaller sizes and the thicker on the larger ones.

Typical sizes of steel clad transformers are shown in Fig. 3. The main part of the case, including the cover, is made of five parts besides the hanger iron lugs, several bolts and nuts and other small accessory pieces.

The steps in making the cover are shown in Fig. 4. The first operation is blanking out the cover from the sheet, the type of machine used being shown in Fig. 1. The blank is so shaped that the finished cover does not need a trimming operation to give an even edge. The next operation is to form the cover into shape by the use of the press shown in Fig. 2. The finishing operation, made on a relatively small punch press, is to punch out the holes used for bolting the cover to the case.

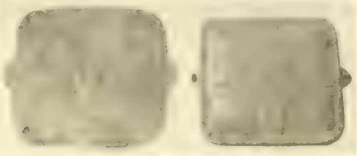


FIG. 4—THE TWO OPERATIONS BY WHICH THE COVER IS FORMED

Forming the top rim and base for the case, the various steps of which are shown in Fig. 5, is a more complicated process than that of making the cover. The first step is a blanking operation from the large sheet. In this case, the blank cannot be made so as to eliminate the trimming operation required to give a straight edge on the finished piece. The degree to which the metal must be drawn for this part is much greater than for the cover, and the difference in the characteristics of the sheets from time to time, is enough that a blank of fixed area would not always provide sufficient metal to make the part exactly to size. The next two steps are drawing operations, two stages being necessary to avoid tearing the metal. For sheets having a thickness of 0.109 inch and greater, it is necessary to anneal between the drawing operations, using ovens such as shown in Fig. 7. Also for the thicker sheets, it is necessary to pickle the blanks in an acid solution to remove the scale. If the scale is not removed in the drawing operations, it will score the metal and in extreme cases will start a tear. It is especially necessary to pickle those pieces which have been annealed between draws.

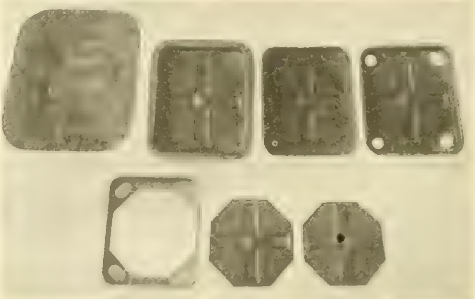


FIG. 5—OPERATIONS IN MAKING THE TOP RIM AND BASE

The next operation is to punch out the holes for the primary and secondary bushings and the two holes at the sides of the rim which are used by the bolts which clamp the small castings, by which the transformer is lifted, to the case. These same bolts engage the tops of the braces extending upward from the transformer proper, and thus hold it in the case. All of the six holes just referred to are punched at the same operation. The

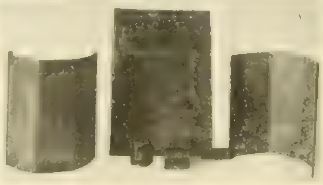


FIG. 6—THE STEPS IN MAKING THE SIDE WALLS FOR THE CASE
Hanger iron lugs are shown in the foreground.

next step is to punch out the bottom of the pan which has been formed by the preceding operations. This punched out part forms the base of the final transformer tank. It will be noted that a cross has been pressed into this bottom piece in order to stiffen and adapt it to form the base of the case. The final operation on this base piece is to turn over its edge so as to form the best condition for welding, as shown in Fig. 9.

The several steps in forming the side walls for the case are shown in Fig. 6. The first operation is cutting the blanks, which is done on shears of the type shown in Fig. 10. The next operation is one of bending the sheets on the press, shown in Fig. 11. The final operation performed on one of the halves only, is the punching of the hole for the outlet plug.

The various parts of the case are shown in one view in Fig. 12. In assembling the case, the two sides are brought together as shown in Fig. 8. They are first tacked together in several places to hold them while the final welding seams are being made. As shown in Fig. 8, the parts are so shaped as to make the best possible condition for welding. The two sides now forming a tube, are inserted into the top rim. and the joint welded. The base is then placed in position and welded, as shown in Fig. 13.

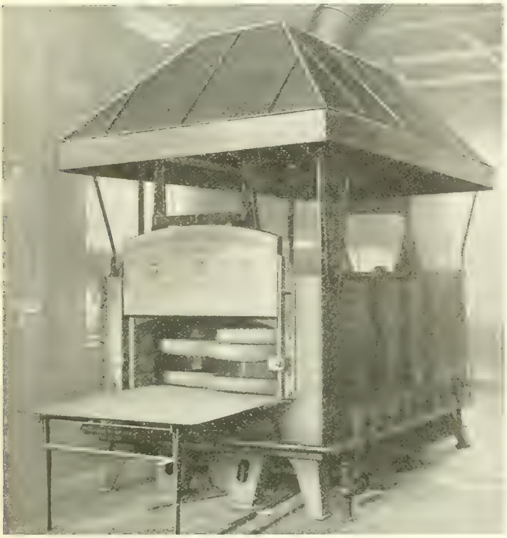
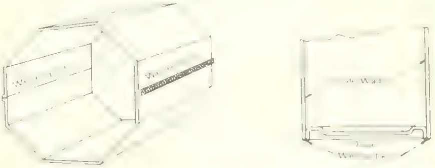


FIG. 7—OVENS FOR ANNEALING THE TANK RIMS

The hanger iron lugs, as shown in Fig. 6, are also made of sheet metal. The first operation is to form the blank and the succeeding one to punch out the hole and the final one to bend into shape. These hanger lugs are spot welded to the tank, as shown in Fig. 14, preliminary to welding around all the edges. The welding around the edges, in addition to the spot welding is to give additional strength, since a failure at this point in service would be a very serious matter. Fig. 15 shows how the hanger irons are bolted to these hanger lugs, adapting the transformer for mounting on the pole cross-arms. The hanger irons consist of two pieces bent into shape from hot rolled wrought iron bars. The spacing of the holes in the hanger irons is made so as to adapt the same iron to as many different sizes of transformers as possible.



FIGS. 8 AND 9—LOCATION OF WELDED SEAMS

After welding, the tanks are tested for leaks, are inspected to see that the welds have been properly made and are tested with a gauge which just fits when the dimensions are acceptable to the assembling department.

The lead outlet bushings are now babbited into the case, a special tool, which holds the bushing in its correct position, being used to facilitate this operation, as shown in Fig. 16. The tank is then ready for its protective coating.

The end frames are also made of sheet metal as is shown in Figs. 17 and 18. The magnetic circuit and windings are not included in this figure, in order that the relation of the various parts of the end frame construction may be more easily understood. The upper and lower end frames shown in this figure are made from sheet metal, and the two pieces are identical for the same transformer. The steps in making these pieces are first a blanking and then a bending operation. The wrought iron pieces for holding the transformer down in the tank are spot welded together and to the upper end frame, three parts thus forming a single piece. The top end frame is attached to the lower frame by the use of the locking irons shown, which

FIG. 10—SHEARS USED IN BLANKING OUT SIDE WALLS AND OTHER SIMILAR WORK

take the strain when the transformer proper is lifted by the top end frame. The relation of the end frames to the magnetic circuit and winding is shown by Fig. 19.

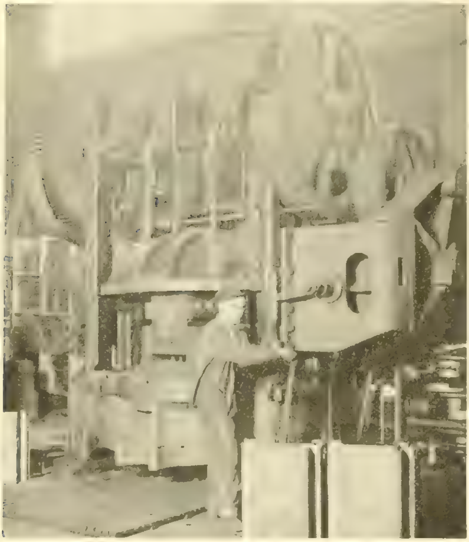


FIG. 11—PRESS WHICH FORMS THE TANK SIDES

The only castings used in the entire transformer are the small lifting lugs, which are bolted to the case, as shown in Figs. 3 and 15. The same bolt which attaches these castings to the case, also engages extensions from the top end frames; thus, holding the transformer down in the case.

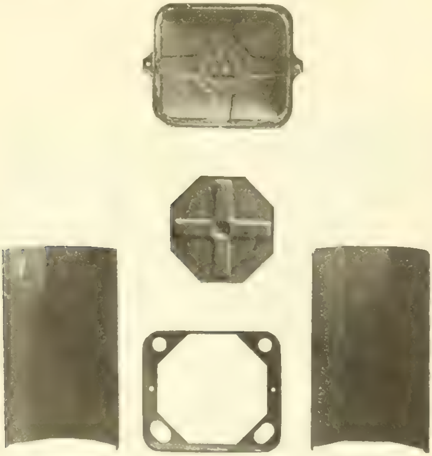


FIG. 12—PARTS FOR CASE OF 15 KV A TRANSFORMER

WEATHER-PROOF FINISH

The protection of transformer cases is an entirely different matter from the protection of roofs or other applications of sheet metal. The surfaces of the transformer cases in service are kept warm by the generation of heat in the coils and magnetic circuit, the heat from the latter continuing as long as connections are maintained to the line. Moisture cannot continue on the surface for any length of time and therefore, the conditions of operation, from the standpoint of weather protection, are most favorable.

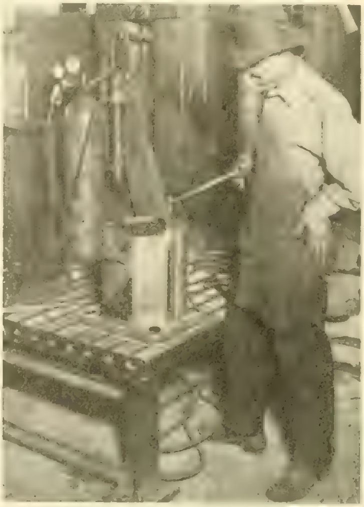


FIG. 13—OXY-ACETYLENE WELDING

A study of the behavior of cast-iron tanks when subjected to the action of the weather, shows that unless protected with a weatherproof finish the cast-iron rusts very heavily, but that a coat of almost any sort of paint or Japan will prevent rusting for an indefinite time. The reason for this seems to be that the paint or Japan soaks into the rough surface and cannot be dislodged, the action of the weather being merely to wear

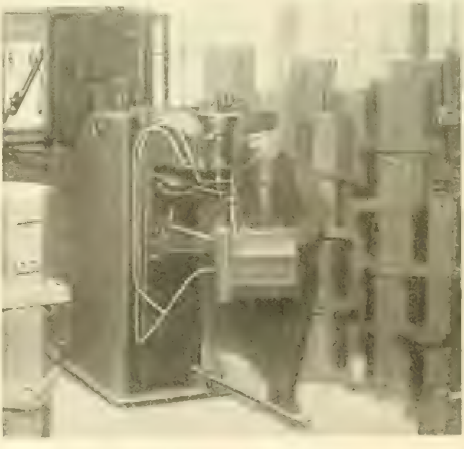


FIG. 14—SPOT WELDING HANGER LUGS IN POSITION WITH AN ELECTRIC WELDING MACHINE

Preliminary to final welding around the edge with oxyacetylene flame.

it thinner. An examination of transformers which have been in service for from ten to fifteen years still showed a continuous protective coating.

Weather protection of sheet-metal surfaces presents, however, a somewhat different problem from that of cast iron. If paint is applied to an ordinary sheet metal surface, an action is sometimes noticed which appears to be a gradual drying out of the paint and then the appearance of minute cracks. Under the worst conditions, these may become larger until the paint begins to flake and strip from the surface. The difficulty encountered here is that the surface is normally very smooth, and the protective coating does not adhere to it in the same way as it does to cast iron. This suggested that if the surface should be treated so as to cause it to resemble that of cast iron, the question of the weather protection of the sheet metal would be simplified. The obvious solution of the problem, therefore, was the use of a sandblast to obtain a roughened surface as a basis for the protective coating. The sandblast removes all scale and dirt, gets right down to the sheet metal itself, and so roughens the surface that the protective coating adheres so closely that it becomes integral with it.

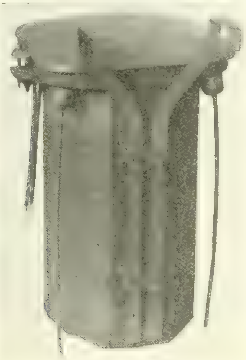


FIG. 15 15 KV-A STEEL CLAD TRANSFORMER
With hanger iron in position for pole mounting.

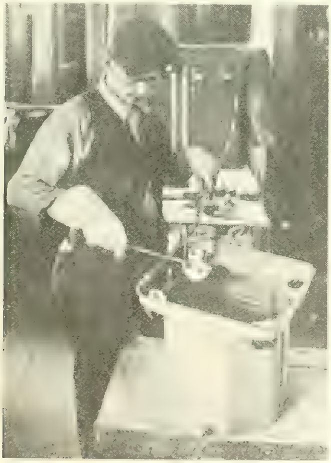


FIG. 16—BABBITTING BUSHING IN TANK

The weather proofing as practiced consists of the following operations:—

1—Sandblasting to remove the scale and dirt and to roughen the surface.

2—Applying and baking on a coat of priming paint.

3—Applying and baking on a coat of finishing paint.

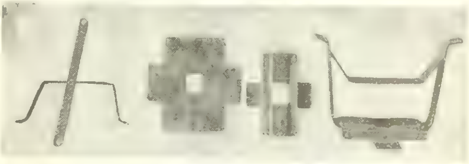


FIG. 17—THE SEVERAL STAGES IN MAKING THE TRANSFORMER END FRAMES

The finishing coat is heavy in oil and is designed to withstand the wear of the elements. Its color is dark gray, the purpose being to make the transformers as inconspicuous as possible when mounted on the pole. This color will merge into the skyline in the same way as the paint used on battleships tends to make them invisible.

The sandblasting equipment is shown in Fig. 20, the doors, of course, being closed when the blast is in operation. The circular table revolves slowly so as to present all the surfaces consecutively to the blast which is directed by the operator. The treatment removes all scale and dirt, leaving a clean and roughened surface.

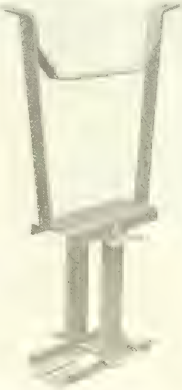


FIG. 18—END FRAMES, LOCKING IRONS AND BRACES OF STEEL CLAD TRANSFORMER

The bushings are next babbitted into the case and the tanks are then coated with the priming paint by dipping, as shown in Fig. 21. The paint fills the tiny scratches left by the sandblasting, penetrates the microscopic ridges and grooves, and becoming integral with the tank surface insures a permanently effective coating which is hardened by the heat treatment next applied.

It is necessary to bake the first coat of paint for several hours at a uniform temperature. An oven, with a truck load of freshly painted tanks, ready for baking, is shown in Fig. 22.

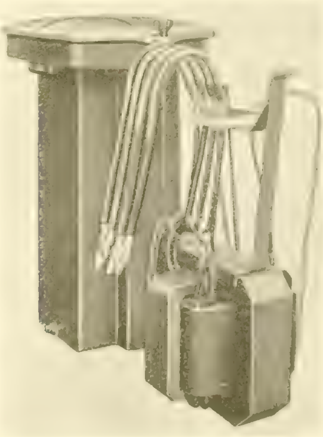


FIG. 19—50 KV-A TRANSFORMER READY FOR MOUNTING IN TANK

After the tanks have been allowed to cool, the finishing coat of paint is applied by a similar dipping and baking process and the weatherproofing is complete. After a final inspection the cases are complete and ready for the mounting of the transformers.

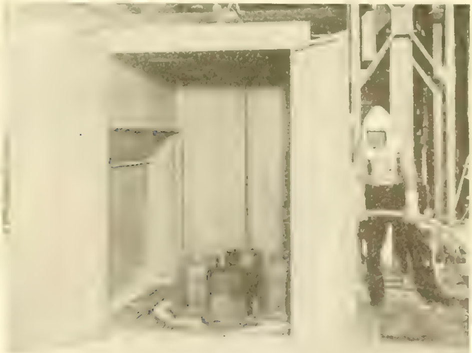


FIG. 20—SAND BLASTING EQUIPMENT

With doors open to show tanks on revolving table. Doors are closed when the blasting is in operation.

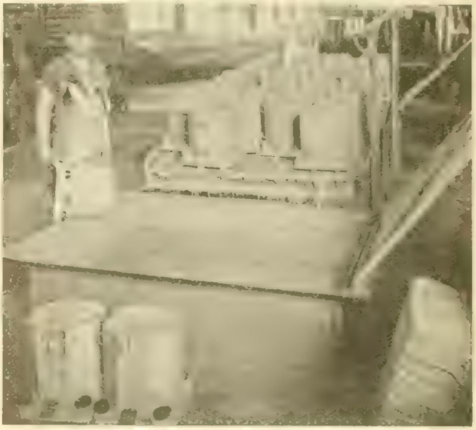


FIG. 21—APPLYING PROTECTIVE COATING BY DIPPING

CONCLUSION

The use of fabricated sheet metal results in characteristics of value in handling, shipment and installation of the transformer and at the same time is favorable to quantity production. The use of sheet metal has a tendency to relieve the present pressure on the production of castings. The manufacturing process involves considerable expensive equipment and an attention to detail which is feasible only when production in large quantities is possible.

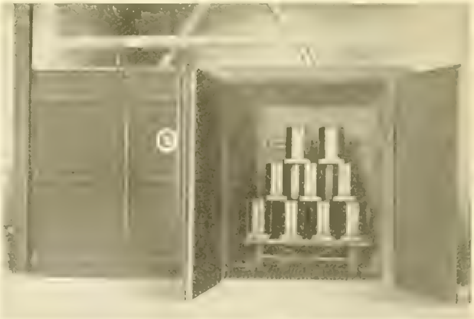


FIG. 22—OVEN FOR BAKING ON THE PROTECTIVE COATING

Switchboard Meter Connections for Alternating Current Circuits—V

Three-Phase, Four-Wire Circuits

J. C. Group

THE THREE-PHASE four-wire circuit consists of a three-phase circuit which is fed by a star-connected generator or transformer bank, in which one end of each of the three-phase windings is connected to a main line, and the other end of each of the three windings is connected to a common or neutral point and a fourth line is taken out from this neutral point. Fig. 62 represents a star-connected generator feeding a three-phase four-wire circuit where lines *1*, *2* and *3* are the main lines and *0* is neutral. The voltages in the three-phase windings are 120 degrees apart, and the phase rotation is assumed to be *0-1*, *0-2* and *0-3*, that is, the voltage is a maximum in phase *2*, in the direction from *0* (the neutral point) to line *2*, 120 degrees after it is a maximum in phase *1* in the direction from *0* to line *1*, and the voltage in phase *3* is a maximum in the direction from *0* to line *3*, 120 degrees after it is a maximum in phase *2*, in the direction from *0* to line *2*, etc. A number of different kinds of load circuits may be connected to a three-phase four-wire system, such as three-phase four-wire circuits where loads are connected between the lines and neutral, any kind of a three-phase three-wire load connected to the three main lines and single-phase loads connected between the main lines, or from any main line to neutral. The current flowing out on any one of the main lines may not return on the other main lines, but may return on the neutral, and for that reason it is necessary to connect a current transformer in each of the three main lines in order to make complete measurements.

The vector diagram, Fig. 63, shows the phase relations of voltages for the three-phase four-wire systems and the currents for a balanced three-phase four-wire load. $E_{1\,0}$, $E_{2\,0}$ and $E_{3\,0}$ represent the voltages from the three main lines to neutral, and with proper consideration of positive directions may represent the generated voltages from the neutral to each line respectively. Voltage $E_{1\,2}$ is equal to $E_{1\,0} - E_{2\,0}$ (vectorially) and being 30 degrees ahead of $E_{1\,0}$ is $\sqrt{3}$ or *1.73* times the voltage to neutral. Likewise $E_{2\,3}$ and $E_{3\,1}$ represent the other main line voltages. The currents for a balanced load are represented by I_1, I_2 and I_3 and are shown lagging behind the voltages to neutral by an angle ϕ in order to cover a load at any power-factor.

It is evident from the physical characteristics of the system that the power delivered to a three-phase four-wire load is equal to the sum of the power in the three phases between the main lines and neutral, and from the vector diagram is $E_{1\,0}\, I_1 \cos \phi + E_{2\,0}\, I_2 \cos \phi + E_{3\,0}\, I_3 \cos \phi$ or for the balanced load is $3\, E_p\, I \cos \phi$ where E_p is the voltage from any phase line to neutral and I the line current.

The connections for measuring the power in a three-phase four-wire circuit with three single-phase wattmeters are shown in Fig. 64. Three current transformers and three voltage transformers are used, the voltage transformers being connected between each of the main lines and neutral and the current transformers being connected in the three main lines. One of the three wattmeters is connected in each phase between a main line and neutral, the same as for a single-phase circuit. Therefore, the power measured by the right hand, middle and left hand wattmeters is $E_{1\,0}\, I_1 \cos \phi$, $E_{2\,0}\, I_2 \cos \phi$, *and* $E_{3\,0}\, I_3 \cos \phi$ respectively, and the sum of these measurements is the same as the general expression derived for the power in the three-phase four-wire system and is correct. This method of measuring the power is independent of unbalanced voltages or currents.

It may also be shown, from the vector diagram in Fig. 63, that the three single-phase wattmeters, connected as in Fig. 64, measure the power correctly for balanced three-phase three-wire loads connected to the three main lines. The line currents for a balanced three-phase, three-wire load are $30° + \phi$, behind the line voltages, and therefore, I_1, I_2 and I_3 may represent the three-phase, three-wire line currents. The right hand wattmeter measures $E_p\, I_1 \cos \phi$, the middle wattmeter $E_p\, I_2 \cos \phi$ and the left hand wattmeter $E_p\, I_3 \cos \phi$, and the sum of the three measurements is $3\, E_p\, I \cos \phi$. But E_p is equal to $1/3 \times 1.73\, E$, where E is the three-phase line voltage and therefore the expression for the power becomes $1.73\, EI \cos \phi$ which is correct for the power in a three-phase circuit for a balanced load at any power-factor.

It may be shown further that the three single-phase wattmeters measure correctly the power for unbalanced three-phase three-wire loads by considering the extreme case of unbalancing, where single-phase loads are taken off between any two of the lines. A vector diagram for these conditions is shown in Fig. 65. I_1 and I_2 represent the line currents when the single-phase load is between lines *1* and *2*, and are shown lagging by an angle ϕ to cover any powerfactor. As current flows in lines *1* and *2* and not in line *3*, the power is measured by the right hand and middle wattmeters. The right hand wattmeter's measurement W_R is $E_{1\,0}\, I_1 \cos (30° - \phi)$ or, expressing $E_{1\,0}$ in terms of the voltage between lines E and omitting the subfigure from I_1, since it is the line current, $W_R = 1/3 \times 1.73\ EI \cos (30° - \phi) = 1/3 \times 1.73\ EI\ (\cos 30° \cos \phi + \sin 30° \sin \phi) = 1/3 \times 1.73\ EI\ (1/2 \times 1.73 \cos \phi + 1/2 \sin \phi) = 1/6\ EI\ (3 \cos \phi + 1.73 \sin \phi)$. The power measured by the middle wattmeter is $E_{2\,0}\ I_2 \cos (30° + \phi)$ or, expressing $E_{2\,0}$ in terms of E and omitting the subfigure from I_2, $W_M = 1/3 \times 1.73\ EI \cos (30 + \phi) = 1/6\ EI\ (3 \cos \phi - 1.73 \sin \phi)$. The sum of the two readings is $EI \cos \phi$ which is the correct power in the single-phase circuit. A similar process of reasoning will show that, when the single-phase load is between lines *2* and *3*, where I_{2A} and I_3 are the line currents, the power is measured by the middle and left hand wattmeters, and when the single-phase load is between lines *3* and *1* where I_{3A} and I_{1A} are the line currents, the power is measured by the left hand and right hand wattmeters, and the final results are the same in each case. It can be seen from the vector diagram that, if the current in the single-phase circuits lags or leads by an angle greater than 60 degrees, one wattmeter reading becomes negative, so that, for unbalanced loads, the algebraic sum of the wattmeter readings gives the correct power.

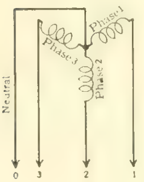


FIG. 62—THREE-PHASE, FOUR-WIRE CIRCUIT FED BY A STAR CONNECTED GENERATOR

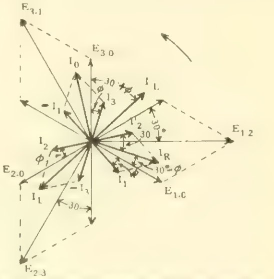


FIG. 63—BALANCED LOAD OF CIRCUIT SHOWN IN FIG. 62 AT ANY POWER FACTOR

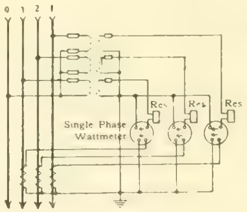


FIG. 64—MEASURING BALANCED AND UNBALANCED THREE-PHASE LOADS WITH SINGLE-PHASE WATTMETERS

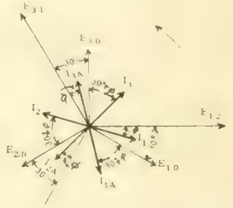


FIG. 65—SINGLE-PHASE LOADS BETWEEN LINES *1* AND *2*, *2* AND *3*, AND *3* AND *1* OF CIRCUIT SHOWN IN FIG. 64

In Fig. 66 are shown the connections for measuring the power in a three-phase, four-wire circuit with one polyphase wattmeter. Three current transformers and two voltage transformers are used, the current transformers being connected in the three main lines and the voltage transformers being connected between two of the main lines and the neutral. The polyphase wattmeter correctly measures the power for any kind of a load of any power-factor, regardless of unbalanced currents, so long as the voltages remain balanced. If the voltages become unbalanced, a small error is introduced due to the voltages from line to neutral not being equal. Fig. 63 is the vector diagram for a balanced three-phase load.

The three current transformers in Fig. 66 are connected in delta, so that the current I_R which flows through the right hand element of the wattmeter is equal to $I_1 - I_2$ (vectorially) and, being 30 degrees ahead of I_1, represents 1.73 times the line current. The voltage coil of the right hand element is connected to the voltage $E_{1\,0}$, and therefore the power W_R measured by this element is $E_{1\,0}\ I_R \cos (30° - \phi)$ or, expressing I_R in terms of the line current I and representing $E_{1\,0}$ by E_p, $W_R = E_p\ 1.73\ I \cos (30° - \phi) = 1/2\ E_p\ I\ (3 \cos \phi + 1.73 \sin \phi)$. The current I_L which flows through the left hand element of the wattmeter is equal to $I_2 - I_3$ (vectorially) and being 30 degrees ahead of I_2 represents 1.73 times the line current. The left hand element is connected to the voltage $E_{3\,0}$, and I_L is $150° - \phi$ ahead of $E_{3\,0}$. The current I_L is taken through the current coil of the wattmeter in the reverse direction from the positive direction assumed for the meter coils in order that the power component of I_L may be in the same direction as $E_{3\,0}$ and produce a positive reading. Therefore, the torque producing reaction in the meter is caused by the power component of I'_L which is equal to, but 180 degrees from, I_L. The power W_L measured by the left hand element is $E_{3\,0}\ I'_L \cos (30° + \phi)$ or, expressing I'_L in terms of the line current I and representing $E_{3\,0}$ by E_p, $W_L = 1.73\ E_p\ I \cos (30° + \phi) = 1/2\ E_p\ I\ (3 \cos \phi - 1.73 \sin \phi)$. The sum of the two measurements is $3\ E_p\ I \cos \phi$ which is correct for a balanced load. It can be seen from the vector diagram that, if the angle of lag or lead becomes greater than 60 degrees, the reading in one element becomes negative, and therefore the actual power is represented by the algebraic sum of the measurements of the two elements.

For unbalanced three-phase four-wire loads there will be considered the extreme case of unbalancing where single-phase loads are connected between the main lines and neutral. Where the single-phase load is between line *1* and neutral, I_1 Fig. 63 represents the current in line *1* and also the current which flows through the right hand element of the polyphase wattmeter, and the power measured by this element is $E_{1\,0}\ I_1 \cos \phi$ which is the correct measurement for the power in the single-phase circuit. The left hand element does not measure any power for there is no current flowing through it. If the single-phase load is between line *3* and neutral, the left hand element measures the power and there is no measurement in the right hand element, for I_3, representing the current in line *3* and the current which flows through the left hand element (in a direction opposite to the arrow) does not flow through the right hand element. The power measured by the left hand element for this case is $E_{3\,0}\,I_3 \cos\phi$ which is correct. If the single-phase load is between line *2* and neutral, I_2 represents the current in line *2* and the current which flows through both current coils of the meter. It is seen from the connections in Fig. 66 that the current I_2 flows through both coils in a direction opposite to the positive direction assumed for the meter coils, but this is correct for a positive reading since in the left hand element the current is $120° - \phi$ ahead of the voltage $E_{3\,0}$, and in the right hand element is $120° + \phi$ behind the voltage $E_{1\,0}$, and the power component of this current which reacts with voltages in the two elements is that obtained by projecting I'_2 (equal to I_2 but 180 degrees from it) on the line of the respective voltage vectors. The current I'_2 is $60° + \phi$ behind $E_{3\,0}$ and the power measured by the left hand element is $E_{3\,0}\,I'_2 \cos(60° + \phi)$ or, $E_p\,I \cos(60° + \phi) = 1/2\,E_p\,I\,(\cos\phi - 1.73 \sin\phi)$. The current I'_2 is $60° - \phi$ ahead of $E_{1\,0}$ and the power measured by the right hand element is $E_{1\,0}\,I'_2 \cos(60° - \phi)$ or $E_p\,I \cos(60° - \phi) = 1/2\,E_p\,I\,(\cos + 1.73 \sin\phi)$. The sum of the measurements in the two elements is $E_p\,I \cos\phi$ which is correct. It can be seen from the vector diagram that if the angle of lag, becomes greater than 30 degrees, the reading in the left hand element will be negative and therefore the actual power is always the algebraic sum of the measurements in the two elements.

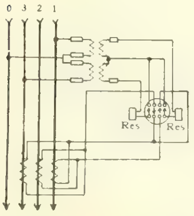


FIG. 66—MEASURING BALANCED AND UNBALANCED THREE-PHASE LOADS AT ANY POWER-FACTOR WITH A POLYPHASE WATTMETER

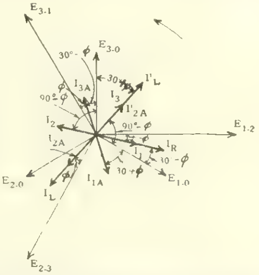


FIG. 67—SINGLE-PHASE LOADS BETWEEN LINES *1* AND *2*, *2* AND *3*, AND *3* AND *1* OF CIRCUIT SHOWN IN FIG. 66

The measurement of power, by the polyphase wattmeter connected as in Fig. 66 for three-phase three-wire loads may also be explained in connection with the vector diagram in Fig. 63. For a balanced load at unity power-factor the line currents are 30 degrees behind the line voltages, but in order to cover balanced loads at any power-factor, I_1, I_2 and I_3, representing the three line currents, are shown lagging behind the line voltages by an angle $30° + \phi$. With the delta connected current transformers the current I_R which flows through the right hand element of the wattmeter is equal to $I_1 - I_2$ (vectorially) and being 30 degrees ahead of I_1 is equal to $1.73\,I$, where I represents the line current. The power W_R measured by the right hand element is $E_{1\,0}\,1.73\,I \cos(30° - \phi)$. But $E_{1\,0} = 1/3 \times 1.73\,E$ and using this value, the expression for the power becomes $1/3 \times 1.73\,E\,1.73\,I \cos(30° - \phi) = 1/2\,EI\,(1.73 \cos\phi + \sin\phi)$. The current I_L which flows through the left hand element of the wattmeter is equal to $I_2 - I_3$ (vectorially) and being 30 degrees ahead of I_2 is equal to $1.73\,I$. The current I_L is $150° - \phi$ ahead of $E_{3\,0}$, but is taken through the current coil of the wattmeter in the opposite direction from the positive direction assumed for the meter coils, and therefore the power component is the same as that obtained by projecting I'_L on the line of the voltage vector $E_{3\,0}$. I'_L is $30° + \phi$ behind $E_{3\,0}$ so that the power W_L measured by the left hand element is $E_{3\,0}\,1.73\,I \cos(30° + \phi)$ or, expressing $E_{3\,0}$ in terms of the line voltage E, $W_L = 1/3 \times 1.73\,E \times 1.73\,I \cos(30° + \phi) = 1/2\,EI\,(1.73 \cos\phi - \sin\phi)$. The total power given by the algebraic sum of the measurements in the two elements is $1.73\,EI \cos\phi$, which is correct for the power in a three-phase three-wire circuit for a balanced load.

For the unbalanced three-phase three-wire loads, the extreme case of unbalancing will be considered where single-phase loads are connected between any two of the three main lines. A vector diagram for these conditions is shown in Fig. 67. I_1 and I_2 represent the line currents when the single-phase load is between lines *1* and *2*, and with the delta-connected current transformers, the current I_R which flows through the right hand element of the polyphase wattmeter is equal to $I_1 - I_2$ (vectorially) and, since the currents combine in phase, is equal to twice the line current. I_R is $30° - \phi$ ahead of the voltage $E_{1\,0}$ and the power measured by the right hand element is $E_{1\,0}\,I_R \cos(30° - \phi)$ or, expressing $E_{1\,0}$ in terms of the line voltage E and I_R in terms of the line current I, $W_R = 1/3 \times 1.73\,E\,2\,I \cos(30° - \phi) = 1/3\,EI\,(3 \cos\phi + 1.73 \sin\phi)$.

It can be seen from the connections in Fig. 66 that for this case the current $-I_2$, after passing through the right-hand element, flows through the current coil of the left hand element of the wattmeter in the direction corresponding to the positive direction assumed for the meter coils. At unity power-factor, $-I_2$ is 90 degrees behind the voltage $E_{3\,0}$ and there is no measurement of power in the left hand element; but for the angle of lag ϕ there is a component of I_2 in phase with $E_{3\,0}$, and since the current flows through the meter element in the opposite direction to the voltage, the measurement in the element is negative and equal to $-\,E_{3\,0}\,I_2 \cos(90° - \phi)$ or, expressing $E_{3\,0}$ in terms of the line voltage E and omitting the sub-figure from I_2, $W_L = -\,1/3 \times 1.73\,EI \cos(90° - \phi) = -\,1/3 \times 1.73\,EI \sin\phi$. The algebraic sum of the measurements in the two elements is $EI \sin\phi$ which is correct for the single-phase circuit.

In case the single-phase load is between lines *2* and *3*, I_{2A} and I_3 represent the line currents, and with the delta-connected current transformers the current I_L which flows through the left hand element of the wattmeter is equal to $I_{2A} - I_3$ (vectorially) and, since the currents combine in phase, is equal to twice the line current. I_L is $150° - \phi$ ahead of $E_{3\,0}$ and flows through the current coil of the wattmeter in the opposite direction to the voltage $E_{3\,0}$ so that the power components of I_L which reacts with the voltage in the meter is that obtained by projecting I'_L on the line of the voltage vector $E_{3\,0}$. I'_L is 30° + ϕ behind $E_{3\,0}$ and the power W_L measured by the left hand element is $E_{3\,0}\, I'_L \cos (30° + \phi)$ or, expressing $E_{3\,0}$ in terms of the line voltage E and I'_L in terms of the line current I, $W_L = 1/3 \times 1.73\, E \times I \cos (30° + \phi) = 1/3\, E\, I\, (3 \cos \phi - 1.73 \sin \phi)$. The current I_{2A} after passing through the left hand element, flows also through the right hand element of the wattmeter in the opposite direction to the positive direction assumed for the meter coils. At unity power-factor I_{2A} is 90 degrees behind $E_{1\,0}$ and there is no measurement in the right hand element, but for the angle of lag ϕ the power component of I_{2A} which is in phase with $E_{1\,0}$ is that obtained by projecting I'_{2A} (equal to and 180 degrees from I_{2A}) on the line of the voltage vector $E_{1\,0}$. I'_{2A} is 90° − ϕ ahead of $E_{1\,0}$ and the power measured by the right hand element is $E_{1\,0}\, I'_{2A} \cos (90° - \phi)$ or, expressing $E_{1\,0}$ in terms of the line voltage E and representing I'_{2A} by I, $W_R = 1/3 \times 1.73\, EI \cos (90° - \phi) = 1/3 \times 1.73\, EI \sin \phi$. The algebraic sum of the measurements in the two elements is $EI \cos \phi$ which is correct for the single-phase circuit.

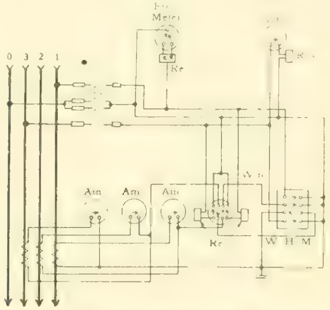


FIG. 68—MEASURING LINE CURRENTS WITH THREE AMMETERS

In case the single-phase load is between lines 3 and 1, I_{3A} and I_{1A} represent the line currents. I_{3A} flows through the left hand element of the polyphase wattmeter in the opposite direction to the small arrow in Fig. 66 or in the same direction as the voltage $E_{3\,0}$, and is 30° − ϕ ahead of $E_{3\,0}$, therefore the power measured by the left hand element is $E_{3\,0}\, I_{3A} \cos (30° - \phi)$ or, expressing $E_{3\,0}$ in terms of the line voltage E and omitting the sub-figure from I_{3A}, $W_L = 1/3 \times 1.73\, EI \cos (30° - \phi) = 1/6\, EI\, (3 \cos \phi + 1.73 \sin \phi)$. The current I_{1A} flows through the right hand element and is 30° + ϕ behind the voltage $E_{1\,0}$ so that the power measured by the right hand element is $E_{1\,0}\, I_{1A} \cos (30° + \phi)$ or, expressing the voltage $E_{1\,0}$ in terms of the line voltage E and omitting the sub-figures from I_{1A}, $W_R = 1/3 \times 1.73\, EI \cos (30° + \phi) = 1/6\, EI\, (3 \cos - 1.73 \sin \phi)$. The algebraic sum of the measurements in the two elements is $EI \cos \phi$ which is correct for the single-phase circuit.

Fig. 68 shows a group of meters on a three-phase four-wire circuit where three ammeters are used. The three current transformers are delta-connected but the ammeters are connected inside the delta so that they give a reading of the line currents. The measurement of power by the polyphase indicating wattmeter and the watthour meter is similar to that outlined in connection with Fig. 66, the current coils of the two meters being connected in series. The frequency meter and the voltmeter are connected across one of the voltage transformers from line to neutral. If the voltmeter is provided with a proper coil and calibration, it may be connected between the wires from the voltage transformers, corresponding to lines 1 and 3, so that the reading would be the voltage between the main lines.

In Fig. 69 are shown the connections for a polyphase wattmeter and one ammeter, used with an ammeter switch by means of which the ammeter may be connected to read the current in each of the three main lines. The ammeter switch may be used with any combination of meters on the three-phase four-wire circuit, but it is shown here only with the polyphase wattmeter in order to simplify the explanation of the connections.

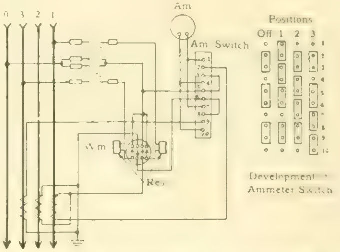


FIG. 69—MEASURING LINE CURRENTS WITH ONE AMMETER

The current transformers are delta-connected for use with the polyphase wattmeter exactly the same as in Fig. 68. The development of the ammeter switch shows how the connections are made within the switch for the different positions. For the off position, points 1, 4, 7, and 10 are open so that the ammeter is entirely disconnected, and points 2 and 3, 5 and 6, 8 and 9 are respectively connected together. The current from the current transformer in line 1 flows through the right hand element of the wattmeter to point 5 on the ammeter switch, from point 5 to point 3 and returns to the transformers on the wire from point 2. The current from the current transformer in line 2 flows through the left hand element of the wattmeter to point 6 on the ammeter switch and out from point 5 through the right hand element of the wattmeter and returns to the transformer. The current from the current transformer in line 3 flows to point 9 on the ammeter switch, from point 8 to point 6, and from point 6 through the left hand element of the wattmeter and returns to the transformer. For position 1, points 7 and 10 are open and point 1 and 2, 3 and 4, 5 and 6, 8 and 9 are respectively connected together. The circuits for the current transformers in lines 2 and 3 are the same as in the off position, but the current from the current transformer in line *1* flows through the right hand element of the wattmeter to point *5* on the ammeter switch, from point *5* to point *3*, out from point *4* through the ammeter (thus giving the reading of the current in line *1*) to point *1* on the ammeter switch and returns to the transformer on the wire from point *2*. For position *2*, points *1* and *10* are open and points *2* and *3*, *4* and *5*, *6* and *7*, *8* and *9* are respectively connected together. The circuits for the current transformers in lines *1* and *3* are the same as for the off position, but the current from the current transformer in line *2* flows through the left hand element of the wattmeter to point *6* on the ammeter switch, out from point *7* through the ammeter (thus giving a reading of the current in line *2*) to point *4* on the ammeter switch, out from point *5* through the right hand element of the wattmeter and returns to the transformer. For position *3*, points *1* and *4* are open and points *2* and *3*, *5* and *6*, *7* and *8*, *9* and *10* are respectively connected together. The circuits for the current transformers in lines *1* and *2* are the same as for the off position, but the current from the current transformer in line *3* flows to point *9* on the ammeter switch, out from point *10* through the ammeter (thus giving a reading of the current in line *3*) to point *7* on the ammeter switch, from point *8* to point *6* and from point *6* through the left hand element of the wattmeter and returns to the transformers.

Electricity in Motion Picture Studios

H. F. O'Brien

IN DISCUSSING the subject of electricity in the motion picture industry, it may be well to briefly review the history of this industry which had its conception a little more than twenty years ago since which time it has risen from insignificance to the fifth greatest industry in the United States.

It is said that an argument over a horse race started the experiments that finally resulted in successful motion picture photography. Two race horse men had an argument as to whether or not a horse, while running, ever had more than two feet on the ground at one time. To settle the argument 24 threads were stretched across the track and each thread attached to a camera shutter. As the horse ran down the track these 24 cameras took 24 pictures covering a brief period of time. The argument was settled, but no successful way of showing the continuity of action was developed, because they did not have a flexible substitute for glass. Some years later, it was found that celluloid could be substituted for the glass photographic plates. This enabled Edison to perfect his kinetescope or peephole machine which was first demonstrated at the Columbian Exposition in 1893.

Two inventors, one in New York and the other in London got several ideas from Edison's invention and finally developed a crude projection machine. The first projected motion picture was shown in a New York basement in 1895. Progress was slow during the next ten years, and even as late as 1905 the motion picture show was very much of a novelty, but by January 1907 there were 1200 movie theatres in New York City alone. There are now approximately 17 200 motion picture theatres in the United States. It was just about this time that the demand for films from these 1200 theaters became a real problem, and the production of films became a small industry. We can all look back and remember the crude photoplays of those days. Practically all of these were taken entirely by sunlight and the photography was such as would not be tolerated in even the lower price theaters of today.

All phases of the motion picture industry have witnessed wonderful development since 1907. Great producing and exchanging corporations have come into existence, giving solidarity to the industry. Intensive scientific research has made marvelous development in the photography and the effects secured.

The standard motion picture is a strip of celluloid about 1¼ inches wide, in reels ordinarily 1000 feet long. In witnessing a modern photoplay production, you probably never consider that the picture on the screen which may be 15 by 20 feet is the magnification of a ¾ by one inch picture on a strip of celluloid, and that, at normal speed, you see 16 different pictures every second, each one separated from the succeeding one by a single black line about 1/32 of an inch wide, so that when you view one of our modern five reel dramas you have seen approximately 90 000 different pictures. Bearing these facts in mind it is easy to understand that the utmost care must be taken in the production and projection of motion picture films to produce harmonious and pleasing results, such as are enjoyed by theater patrons of today. Without electricity this could not be accomplished.

The modern motion picture studio comprises different departments, each with its own particular task to perform. Practically everyone of these departments uses electricity in its work. For instance, in the laboratory, electricity is used for heating tanks filled with solutions used in developing; it furnishes light and power for the printing machines, runs the motors on the perforators, polishers, drying drums and ventillating fans. Electricity drives all the wood working machines in the carpenter shops where the most skilled wood workers and carvers will be found, making the artistic furniture and other settings used on the stages. You may see anything from a Pullman car interior to the bridge of an ocean liner, or a very large interior of a Japanese temple or a Roman palace.

Every large studio has its blacksmith shop, garage and machine shop where electricity furnishes motive power. There are also the projection rooms where the film is shown several times before it is finally edited and completed. Each of these is a minature theater. Generally, one of these rooms is nicely fitted up; for it is here that the final runs are made in the presence of the officials, directors, camera men and the stars who took the leading roles.

ILLUMINATING THE STAGES

The stages proper are of one of three different varities, either open air, glass or enclosed; the most recent trend being towards the closed stage which excludes practically all sunlight. One of the largest West Coast studios started out to use open and glass stages exclusively. They now have one glass covered stage, no open stages, five enclosed stages and are building their new stage 125 by 300 feet entirely enclosed.

The illumination of the "sets", as the stage settings are called, is an interesting problem. It is seldom that sunlight is the only light used, even in Southern California. Sometimes there is a combination of sunlight with artificial light, but obviously on the enclosed or "dark" stages, all the illumination is artificial. This may seem extravagant to those not acquainted with the industry, but experience has shown that the use of sunlight alone gives a very flat picture and, unless handled skillfully, may produce some annoying results in changing shadows. There are two principal classes of artificial light, the "hard" and the "soft". The soft lights are obtained largely from Cooper-Hewitt mercury vapor tubes, while the carbon arc gives the intense light needed to develop the high lights and accentuate any particular feature.

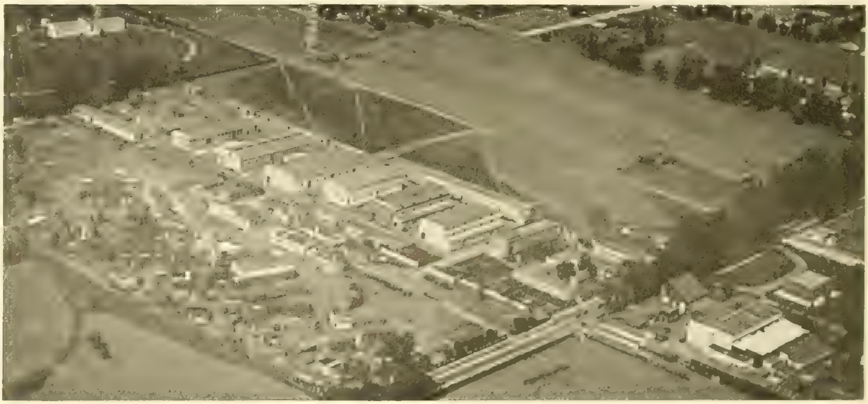


FIG. 1—AIRPLANE VIEW OF THE ROBERT BRUNTON STUDIO AT LOS ANGELES, CALIFORNIA

Eighteen different motion picture companies are producing pictures at these studios. Over 1000 hp in motors and 680 kw in generators are installed here.

Considerable skill is required to secure the proper illumination of the "set", for the theater going public have been educated to expect excellent results and mediocre photography is not tolerated. You can imagine some of the difficulties encountered in securing the proper illumination if you will consider; first, that all of the numerous lamps used must be placed entirely out of the camera's range. Second, no conflicting shadows can appear. This alone is a problem. Third, unless proper "back-lighting" is used the back-ground of the picture will appear very flat and spoil your conception of the depth of the room. Fourth, it must be possible to synchronize all of the lighting effects with the action of the picture.

Great ingenuity has been displayed in meeting the numerous problems in illumination that are always occurring at the studios. This same trait holds good in practically every department. The writer has often admired the spirit that exists in all the studios, and that is, that "nothing is impossible around a studio". For instance—one new studio had to have a large amount of direct current available on a certain day; it looked like it would be impossible to secure motor-generator sets during the war period. It was impossible to secure large ones, so they went on a still hunt and located four smaller sets of from 50 to 100 kw capacity. These sets were moved from various locations to a temporary building at the studio. About 600 kw capacity in transformers was installed, a temporary wooden switchboard was constructed, the whole plant was put in service almost over night and was giving satisfactory operation on schedule time.

Ordinary illumination would fall very flat in the movies; for example, a man enters a darkened room in a night scene and lights a cigarette. You see him strike the match and hold the light to his cigarette, his whole face is illuminated by the glowing "match", just as it would appear to the eye under normal conditions, but if the ordinary match was employed in the picture it would appear as a grey haze only, so it is necessary to use a specially constructed miniature arc from which the cigarette is lighted.

The lighting load at a large studio reaches considerable proportions at times. For example,—large exteriors use more than 8000 amperes or approximately 900 kilowatts in lights. It is not unusual for a large interior scene to run up to 600 kilowatts. While the method of lighting varies at the different studios, there will generally be from 50 to 75 percent direct current. At the larger studios there are from 6 to 25 separate companies "shooting" at the same time. The larger studios often have as much as 700 kw capacity in motor-generator sets.

WIRING THE STAGES

Some novel systems of wiring the stages have been installed at different studios to place the lighting of an entire set under the immediate control of one person. The advantage of such a system is obvious as it enables the director to secure any lighting effect desired. Two studios employ a scheme of using electrically-operated magnetic-contactor switches on the several different feeder circuits supplying the set. These switches can be controlled either singly or in groups by means of push buttons connected with a flexible cable so that they can be carried to any desired place on the set. With this scheme either one or all of the lights can be controlled by a single button. In most studios, however, "location switchboards" using knife switches are employed for this purpose.

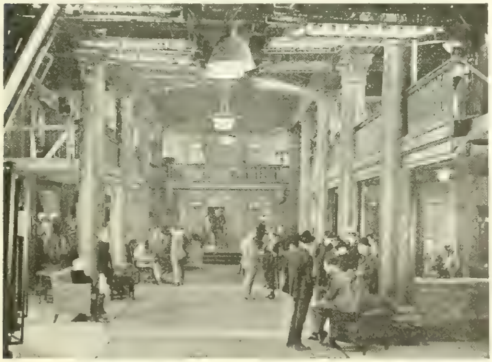


FIG. 2—HOTEL SET IN METRO PICTURE "ALIAS JIMMY VALENTINE."
Showing some of the artificial lighting employed.

SOME ELECTRICAL PROBLEMS TO BE CONSIDERED

Voltage regulation is one of the principal problems at a motion picture studio. Both carbon arc and the Cooper-Hewitt lamps are susceptible to voltage variation and it is surprising to find what disastrous results in photography can be obtained if the camera happens to synchronize with the variations for a while and then "get out of step". Many thousands of feet of film have been ruined on this account.

A very flat voltage regulation is desirable, and this must be maintained over wide ranges of load. It is also desirable to employ the three-wire distributing system throughout the stages on account of the economy in copper and the absence of large and unwieldly conductors. In order to solve this problem of obtaining this flat voltage regulation on a three-wire system over wide ranges of load, the writer in conference with two chief electricians from the largest West Coast studios suggested the use of the three-unit motor-generator set for this application.

THREE UNIT MOTOR-GENERATOR SETS

The three-unit set solved the problem, for by connecting the two generators permanently in series, the three-wire system is secured and no accessory equipment is needed to provide for unbalancing, as each generator can be loaded independently of the other. The first three-unit set installed at a studio has been in successful operation for more than two years and practically all of the West Coast studios are installing similar equipments.

PROBLEMS FOR THE POWER COMPANY

The motion picture studio is not the most desirable load from the power company's viewpoint. The load factor is quite low and there are a large number of transformers and induction motors that often run at very light loads for considerable periods. On the other hand the studios use considerable quantities of light and power, the bills at the larger studios averaging almost $1000 per month, light and power dividing the honors almost equally. Some of the latest 300 kw motor-generator sets installed at the studios have been supplied with synchronous instead of induction motors. Several large synchronous sets will be installed during the coming year in the Los Angeles district. These will do much towards improving the power-factor of these studio loads as they often run lightly loaded for considerable time and they can be set for leading power-factor.

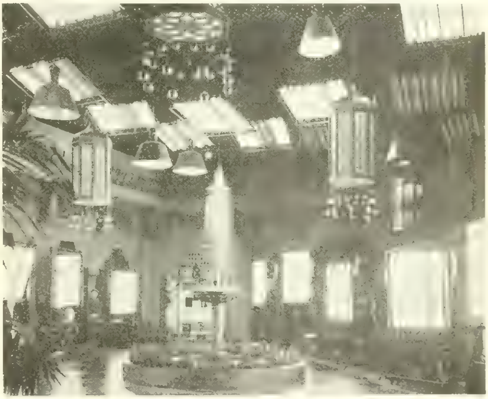


FIG. 3—A SPLENDID EXAMPLE OF GOOD ILLUMINATION
This represents the interior of an Indian temple from the Metro photo play "Hope". All the lights were not on when this photograph was taken, but every detail shows clearly in the original print

TAKING ELECTRICITY WITH THEM

When a movie company leaves the studio to go out on "location", they generally provide some means of obtaining a considerable amount of electric power to illuminate the scene of action. Southern California is covered with a network of power transmission lines. It is also a remarkable fact that in Los Angeles County may be found every kind of an exterior setting from a New England home to a Japanese abode. The natural scenery provides everything that romance and drama could demand. The ocean, the mountains with their snow capped peaks, the sun baked desert, and beautiful valleys can all be reached in two hours run by auto.

Because of these favorable circumstances, some of the studios have portable motor-generator sets, mounted on trailers so they can easily be transported to the locations. These portable sets are complete with both alternating-current and direct-current switchboards and the 2200 volt motor is run directly off the nearest 2200 volt line.

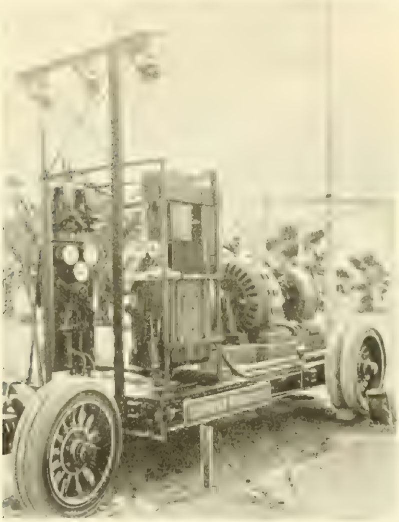


FIG. 4—LOIS WEBER PORTABLE MOTOR GENERATOR SET FOR LOCATION WORK

Showing the direct-current generator panel on the left, and alternating-current control equipment, consisting of an auto starter and 2200 volt oil circuit breaker and a box containing the integrating watthour-meter and transformers.

Where there is no power line handy or where it would be difficult to obtain sufficient direct-current they take along a portable engine-driven set and generate direct-current on the location. These engine-driven sets have been sent as far away as Montana and one Company is expecting to take two of them to Europe in May. Both the portable engine-driven and motor-generator sets have been built in capacities up to 100 kw and the three-unit idea has been carried out in these equipments, because of the advantages of using two generators.

STUDIO SUBSTATIONS

All of the studios are giving considerable care and attention to the design of their substations and the installation of their electrical equipment for continuity of service is most important. The rapid expansion of the industry in Southern California has forced the Southern California Edison Co., on whose system practically all the West Coast Studios are located, to adopt the following rule, that wherever more than about 400 k.v.a. capacity is required, they run a 15 000 volt, three-phase line to the studio sub-station and step-down in a bank of transformers to 2200 volts.

Power at 2200 volts is supplied to the large motor-generator sets and also to other banks of transformers where the voltage is again reduced to 440-220-110 volts for lighting and power circuits. Very complete switchboards are provided for distributing both direct and alternating-current. The motor-generator sets are operated in parallel on a common bus and circuit breakers are provided on all stage feeder circuits.

The studios deserve much credit for the manner in which they have observed the various code rulings as well as the rulings of the California State Accident Industrial Commission. Viewed from the standpoints of good engineering, neatness and the elimination of hazards, their substation installations and distribution systems are not equalled or surpassed by many other large industrial concerns, and many smaller ones could profit by their good example.

FIG. 5—120 KW, THREE UNIT, MOTOR-GENERATOR SET
At Robert Brunton Studios.

THE OUTLOOK

It is difficult to imagine what developments will be witnessed in the motion picture industry, but even the 17 000 odd motion picture theaters in the United States are not the only market for the output of our studios. American films are much in demand in foreign countries. During the next few years, we will witness wonderful developments in the use of motion picture films for industrial exploitation, commercial education, general publicity, advertising and selling. Experiments are being carried on in Los Angeles at present that indicate that color photography may soon be a commercial possibility. We will see more general use of the rapid speed camera for analyzing motion and increasing human efficiency. The present developments in portable projectors indicate a more general use of films for varied purposes. Certainly much can be reasonably expected and the outlook is most promising.

Proposed Reorganization of N. E. L. A.

M. H. Aylesworth
Executive Manager,
National Electric Light Association

CHANGING conditions in the use and regulation of electricity have brought about an immediate need for greater expansion of the National Electric Light Association, coupled with a definite national program which shall assure the continued success of the Association as the national representative of the electrical industry.

Following a general survey made by the executive manager at the request of the national executive committee, upon the recommendation of President Ballard, it was determined to undertake a program of expansion. In answer to a general letter written by the executive manager to executives of all member companies, came a demand for increased service in practical co-operation, which resulted in immediate reorganization of the national headquarters staff. The executive manager will generally direct the work of the Association, including the appointment and direction of the headquarters staff, under the supervision of the president, vice-presidents, and national executive committee.

The organization at headquarters has been divided into five departments, under the direction of the executive manager and acting secretary.

Mr. Fred W. Herbert, superintendent of the company service department, is in charge of the rate book and rate research work, which heretofore has been carried on in Chicago but which lately has become part of the centralized organization. This department is co-operating also with accounting committees and is prepared to give service to companies, large or small, in the matter of technical accounting, rates, valuation, production, service, or other problems. In so doing, this department will act as a clearing house for information, experience, statistics and all such matters, thus giving to small and large companies alike the advantages of practical developments by the other company-members.

The department of publicity is under the direction of Mr. George F. Oxley, director of publicity, who will supervise the gathering of educational propaganda from all parts of the country, which will be disseminated to all member companies and to the public as a whole. As part of the campaign to inform the public on all matters affecting the electrical utilities, member-companies throughout the country will be aided in carrying on this work and in turn will be called on for assistance. This department will assist in the organization of state committees on public utility information and will act as a clearing house for the committees already formed and those which will be organized during the coming year. This department recognizes the fact that all publicity problems which are purely local in character or extent must be handled exclusively by local member-companies or by state associations or geographic divisions; but it is conceded that many of the problems and conditions which confront the electric light and power companies are common to all and should therefore be handled through the national department. The department of publicity will supervise the monthly Bulletin of the Association and will distribute to the membership letters of information regarding activities of the Association and developments within or affecting the industry.

Upon the recommendation of the technical section, approved by the national executive committee, an engineering department will immediately be established, under the supervision of a director. This department is about to engage in gathering statistics and formulating a program on the practical engineering problems which today affect the industry, and will deal particularly with inductive interference, the Safety Code and electrolysis.

A department dealing with committee activity has been formed and is under the direction of Mr. A. Jackson Marshall, committee secretary. The service of this department is offered to the various committees to the end that the work of committees may be co-ordinated, duplication of committee activity avoided, and continuity of committee and section activity assured.

The accounting department is in charge of the accounts of the Association, as well as the membership lists and the mailing of all material to the membership.

Many prominent executives of central station companies can testify to the value of the N. E. L. A. Educational courses, which have been taken advantage of by the members of organizations of member companies for many years. As in the past, these educational courses will be available through the department of education, headed by Mr. Fred R. Jenkins, with headquarters at Chicago. The rapid growth of classes in every State is the best illustration of the appreciation of these courses by members of organizations of central station companies.

Renewed interest has been shown in the organization of company sections, and a department operating in conjunction with the committee on company sections and employees' clubs is contemplated. The province of this department will be to assist in the organization of company sections and employees' organizations through correspondence, suggestions and field work where necessary.

While the organization at headquarters was being perfected, the officials of the National Association were obtaining the views of the representatives of member companies in attendance at state association conventions and geographic division conferences, and by written questionaire. As a result of this investigation, a special committee on reorganization was appointed and the completed plan, visualized by a chart and supported by the proposed constitutional amendments necessary to bring about the machinery for the organization, will be submitted to the membership and will be voted upon at the convention at Pasadena, May 18th to 22nd.

On October 1st, 1919, there were five geographic sections of the National Electric Light Association, composed of two or more states, and seven state geographic sections. Twenty state electrical or public utilities associations existed which were not affiliated with the National Electric Light Association, although the electric central-station membership of these twenty state associations were, with few exceptions, Class A members of the National Association.

The field work carried on since October 1st not only has demonstrated that the work of the National Association should be decentralized to a considerable extent, and that the country should be divided into geographic divisions, but that there is a unanimous demand for the program of the geographic sections committee, which provides for the division of the country into thirteen geographic divisions, including Canada, as defined and named on the accompanyng map. The national executive committee may, on its own motion or upon the application of one or more adjacent geographic divisions, modify the boundaries or add to or subtract from the existing number of geographic divisions.

The proposed plan provides two methods of geographic division organization. Within certain geographic divisions there exist strong and active state electrical associations or state public utilities associations, while in others, where no state association machinery exists, the geographic division carries on the activities of the membership within the division. Thus, it will be seen that the Northwest Electric Light & Power Association, for example, may continue to hold its annual convention and its executive conferences or committee meetings without regard to state boundaries, while the proposed Great Lakes Division, for example, composed of the states of Wisconsin, Michigan, Indiana, and Illinois (two of which had been affiliated with the National Association as state geographic sections, while the other two were unaffiliated), will function through a geographic conference, composed of delegates from the four state associations, who will select the officers of the Great Lakes Division and carry on the activities of the National Association within the boundaries of the division, the state associations continuing to function in all local matters and, in addition, carrying on their activities as integral parts of the geographic division of the National Association.

The purpose of geographic division organization is to decentralize, where possible, the activities of the National Association and harmonize the work of the state association, geographic division, and National Association through co-ordination of all committee activities from the state association, through the geographic division, and finally into the executive committees of the National Association. Where state public utilities associations exist, it is proposed that the electric light and power branch or division of the state association affiliate as part of the geographic division.

Assistance in financing the geographic divisions will be provided upon budgetary appropriation from the dues paid to the National Electric Light Association. The needs of each geographic division, in budget form, will be presented for approval to the national executive committee by the representative of each geographic division upon the national executive committee.

Under the proposed plan, there will be four National Sections:—the Public Relations National Section, Technical National Section, Accounting National Section, and Commercial National Section. In addition to these sections, which are really departments of the Associations, there will be general and special committees appointed by the President, whose scope of activity will be territorial or national:—for example, committees on water power development, electrification of steam railroads, electrical resources of the nation, general membership, national public policy.

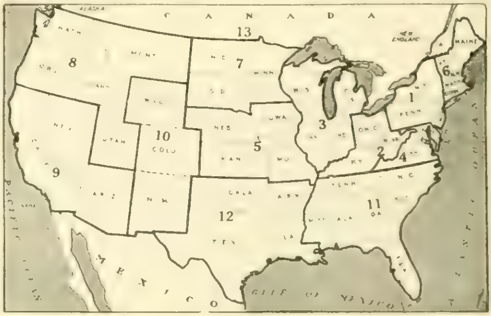


FIG. 1 PROPOSED N. E. L. A. GEOGRAPHICAL DIVISIONS

1. Eastern, 2. East Central, 3. Great Lakes, 4. Middle Atlantic, 5. Middle West, 6. New England, 7. North Central, 8. North West, 9. Pacific Coast, 10. Rocky Mountain, 11. Southeastern, 12. Southwestern, 13. Canadian Electrical Association

There has been comparatively no activity in the National Association pertaining to the relationship of the central station with the public, and the proposed public relations national section is intended to provide machinery for the treatment of all subjects relating to management, public policy and relations with the public, such as federal, state and municipal legislation and regulation; federal, state, and municipal taxation; uniformity of laws, principles of valuation and depreciation under commission regulation; public information through state committees on public utility information; and public utility financing, including customer ownership of securities, municipal ownership, co-operation within the industry and all subjects of similar nature which heretofore have been handled by other national sections and committees of the Association. The officers of the public relations national section will be a chairman, vice-chairman, and executive committee consisting of five members at large, to be elected at the national convention or national conference of the Association, and the chairman of the public relations section of each of the thirteen geographic divisions of the Association. The activities of the public relations section within the geographic division wll be controlled by an executve comittee consisting of the chairman of each of the state associations' committee on public relations. The membership of the public relations national section will consist of the executive officers of Class A member companies.

The proposed technical, accounting, and commercial national sections are substantially the same in character and structure as exist at present, except as their organization is affected by automatic representation from state and geographic divisions, as now proposed.

The chairman of each of the four national sections will become a member of the national executive committee of the Association, and will present to the national executive committee the section program for the administrative year for approval.

The public relations national section will be represented on the national public policy committee by four members of the executive committee of the section, who shall be recommended by the chairman of the section and endorsed by the chairman of the national public policy committee.

The national executive committee of the National Electric Light Association will, in addition to the chairman or representative of each of the thirteen geographic divisions and the chairman of each of the four national sections, have nine members at large (three of whom will be representatives of manufacturing companies), who shall be elected at the national convention or national conference of the association, and the following officers of the National Electric Light Association—president, four vice-presidents, and treasurer, who will also be elected at the national convention or national conference.

This method of selection of the members of the national executive committee is indeed democratic, and results in a more equitable representation from the entire country. Under the existing scheme of organization, the presidents of geographic divisions are not members of the national executive committee but are permitted to attend the meetings of the committee and entitled to cast a total of two votes, while the chairmen of the national sections have not been members of the national executive committee, although permitted to attend meetings of the committee and entitled to one collective vote.

With one or two exceptions, the geographic divisions have either permanently or temporarily organized, and thus the machinery to carry out the program for 1921 and the years to follow is provided, should the program be officially approved by the membership in convention.

The plan of organization provides for complete cooperation between all branches of the industry by inviting the manufacturer, contractor-dealer, and jobber to take a definite part in the work of the Association, but does not contemplate absorption, consolidation, or abandonment of the national organizations of any of the different branches of the industry. In other words, the entire plan of organization is based upon the co-ordination of the interests and activities of the industry in the several states, working through state associations, where they exist, and thence through geographic divisions into the executive committees of the National Association, so that every member company and its individual membership shall have a voice in the program and management of the Association.

Merchandising Electrical Appliances

Wm. T. Reace
Contract Dept.,
Commonwealth Edison Company

As THE electrical appliance has passed from the state of experiment and novelty to that of perfection and necessity, so has the art of merchandising as practiced by the central station.

Central stations have found they must not treat this business as electrical merchandising, but rather as merchandising of electrical goods. By this distinction is meant that electrical goods must be sold in accordance with modern merchandising principles. They cannot be treated on new and special principles just because the word "electrical" is attached. The housewife wishes to buy electrical goods with the same ease and service that she purchases food, clothing or furniture. The same methods of advertising, sales and service that appeal in the case of other essentials, also appeal in the case of electrical appliances. Newspaper advertising is as effective to the electrical goods merchant as it is to the merchant of shoes, dry goods or groceries, but in addition, the central station has at its command a direct method which is automatically selective. The electric light bill must be sent regularly to all customers, and the customers of the central station are the live prospects for electrical merchandise. Stubs of electric light bills, enclosures, return postals, all of these and many other forms of advertising, may be distributed in connection with the electric light bill at a minimum cost. Although the central station will not need to resort to bargain sales or cut prices, occasional clearances of soiled or obsolete stock will be found profitable. Sales efforts of the modern central station will fall in three main divisions.

First:—Sales of wiring supplies and fixtures to dealers, contractors, manufacturers, etc.

Second:—An outside force of salesmen calling on resident customers for the purpose of soliciting merchandise sales.

Third:—The retail store, with possibly several branches in the city, where electrical goods are displayed, demonstrated and sold.

The first division will not be treated in this paper, which will be confined more strictly to household appliances.

Outside salesmen may be divided into two classes; those assigned to certain territory in which they work from the office as a general headquarters, and those who go out on special campaign work, which will be discussed later.

Salesmen under the first class may be appliance salesmen only, or they may be salesmen who sign applications for light and power, and also sell appliances at the time they are making other calls. Some companies have found that it is desirable to encourage appliance selling by all employees who visit the customers premises, such as meter readers, inspectors, etc. Certainly household appliances may be sold efficiently through the efforts of any central station salesman whose duties bring him in contact with resident customers.

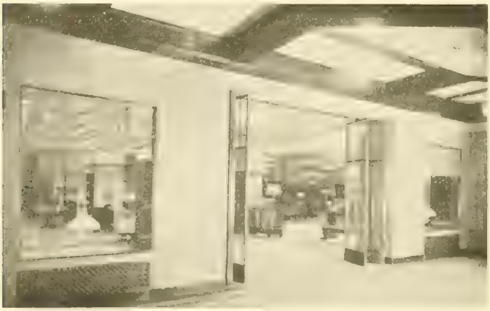


FIG. 1—ENTRANCE AND SHOW WINDOW OF ELECTRIC SHOP FROM LOBBY

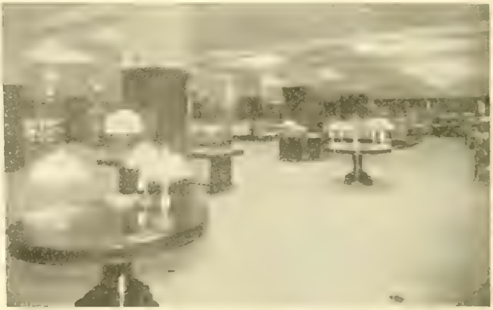


FIG. 2—DISPLAY AND SALES ROOM OF UP-TO-DATE ELECTRIC SHOP

In the second class of work mentioned, namely, campaign work, some varied form of the following procedure has been found successful. Selling crews (an old idea) are formed, and the men under the direction of a crew manager are assigned small blocks of territory. When the assignment has been covered to the satisfaction of a salesman, he reports to his manager and is reassigned. On such work, salesmen should carry a demonstrating sample of a least one article, as for instance, a vacuum cleaner. If the campaign is on small articles, such as irons, toasters and percolators, then often a sample of each can be carried. If arrangements can be made to deliver the sample at the time the sale is made, this method can be found most effective. When a salesman can enter the customer's premises and connect and demonstrate an appliance, there is present a sales opportunity unequalled at any other time. Vacuum cleaners and even washing machines may be handled in this manner to great advantage. An ingenius harness has been devised which enables two men easily to carry a washing machine from the wagon to the customer's basement for demonstration. A demonstration on the customer's premises is half the sales battle.

In the third class, or retail stores, the method of procedure follows the best principles of other retail merchandising. An attractive store, well trimmed windows, efficient salespeople, assorted stock, all are of first importance. In this connection, experience has taught that certain non-current consuming articles, such as flashlights, trays for percolators, clothes racks, etc., must be kept to satisfy the public who expect and wish to buy these articles where they buy their electrical appliances. If they must go to some department store for these things, it will be only natural for them to buy their electrical appliances at the same place. Considering the fact that these non-electrical, but closely related articles, carry good profits, and that they bring the customers into the electric shop, no excuse is necessary for stocking them.

In the last year, deferred payments have proven to be very popular with the public and are a great builder of sales. The central station company is in an excellent position to give deferred payments, because the billing and collecting on merchandise sales can be done along with the electric light bills. Furthermore, these payments will bring the customer into the electric shop a greater number of times yearly, and the monthly arrival of the bill will freshen in their minds the fact that the central station company can furnish any other electric appliances they may desire. Also, past experience with the customer's light bill can be used as a basis in determining the allowance of credit.

Another successful method to secure more frequent visits to the electric shop is the issuing of stamps or coupons redeemable for merchandise handled by the Electric Shop. These coupons are sold at small cost to local merchants who distribute them at a prearranged rate with purchases. Special advertising certificates may be issued by the central station company, and mailed with the electric shop bill. These certificates are redeemable for a certain fixed number of coupons when presented at the redemption desk in the electric shop, or one of its branches. The amount of coupons redeemable may be standard and have no bearing on the amount of the electric light bill.

One branch of merchandising which is yearly showing great increase is that of the industrial appliances—glue pots, soldering irons, branding irons, etc. This class of merchandising differs mainly because of the necessity of engineering service in connection therewith. Many heating appliances and industrial appliances of kindred use must be designed for the individual case in hand, but when such service is given, the remuneration in merchandise sales and monthly income is very good. This field promises large opportunities in the future for the extension of electrical service to industrial needs.

The one great need in the American home today is appliance outlets in walls and baseboards. Central stations should make special efforts to encourage a goodly number of basebard outlets in all homes that are being wired. If the central station is doing the wiring, they can offer a premium to the salesman for each extra baseboard outlet secured and, regardless of who does the wiring, extensive advertising and educational literature should be circulated. Particular attention should be paid to the architect to encourage him in recommending these appliance outlets when submitting building plans.

Another important phase of electrical merchandising is the testing of all articles before they are sold. The larger central stations have found it is very desirable to maintain a laboratory for testing electrical appliances. When a new appliance is offered on the commercial market, the sample or samples are tested both as to workmanship and material, and also as to performance and durability. The smaller central stations, which cannot afford to maintain their own laboratory, can benefit from the findings of such laboratories as the Good Housekeeping Institute, National Testing Laboratory of New York, etc. The National Electric Light Association has appointed a committee to study the possibility of standardization of tests, and possibly the foundation of a central testing laboratory for the mutual use of central stations, contractors, dealers and manufacturers.

The present year of 1920 has opened as a wonderful year for electrical merchandising. On every hand new factories and factory additions are being built. Manufacturers are promising double and triple capacity in the near future. The public is demanding these electrical necessities, and the progressive central station can ill afford to miss this golden opportunity.

THE
ELECTRIC
JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

MAY
1920

Armature Troubles Resulting from Broken Motor Leads

The breaking or burning off of the cables connecting the motors to the car body has been a continual source of trouble in the operation of street railway equipment. This ailment has been chronic and of long standing but only in recent years, since the advent of the light weight ventilating motor, has it developed one of its most serious phases.

In connection with an investigation of roasted armatures on several different properties, a number of cases of broken or burned off cables were associated with this trouble. In all of these cases, the cars were equipped with four light-weight ventilated motors and type K series and parallel control, connected as shown in Fig. 1. Although it was impossible to produce convincing evidence that these two troubles were allied and that the broken cables were responsible for the roasted armatures, the results of the investigations pointed that way, as shown by the following analysis:—

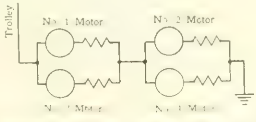


FIG. I—CONNECTIONS OF MOTORS IN SERIES POSITION

Assume that No. 3 motor has an open circuit, due to either field or armature leads being broken or burned off, and that the car is continued in service. With the control in any of the series positions, No. 1 motor receives double the current taken by the No. 2 or No. 4 motors. This means that No. 1 motor has an increased torque and tends to take too much of the load. With the control in any of the parallel positions, the load is equally divided between the three motors, *1*, *2* and *4*. Depending upon service conditions, such as headway, schedule, location of turn-outs on single tracks, congestion of traffic, etc., the amount of series running will vary on different properties, which would determine how much excess current No. 1 motor would receive.

When these conditions are known to exist, the logical thing for the motorman to do is to cut out the No. 1 and No. 3 motors and, operating the car with the other two motors, turn it into the barn for repairs. In a good many cases, however, cars are continued in service with the motors operating in this unbalanced condition, which is discovered only when they are given their regular light inspections, which are usually from 7 to 15 days apart. This means that, operating under these conditions, No. 1 motor has had a number of short time overloads, resulting in overheating of the winding. This overheating may not cause the motor to fail at the time the damage is done, but the insulation has been charred and its life shortened. Some time later the windings on this motor will either ground or short-circuit, due to the poor condition of the insulation, and when examined the motor will be reported as having a roasted armature. It becomes quite difficult to locate the direct cause of the roasting, as the conditions responsible for this trouble may have happened weeks before, and have been remedied without any thought to the possible damage done to the windings of the running mate of the motor with a broken or burned off cable.

SERVICE TEST DUPLICATING ABOVE CONDITIONS.

In order to get some comparative data as to the current taken by a motor when the car is in good condition, and with a motor having a broken or burned off cable lead, a special car was taken out on the road and the following tests and observations were made as shown in Table I.

Conditions of Test

a—Test car was a special and had no passenger load.

b—Ammeter was connected in series with the car circuit breaker.

c—Rail clean and dry.

d—Trolley voltage high, 575 to 585.

e—All observations were taken on a grade at the same location for each test.

Remarks

a—Commutation of motors was sparkless.

b—Wheels did not slip.

c—Slightly increased noise.

d—Car speeds during tests 2 and 3 about normal.

e—Motorman was not able to tell whether one motor was out by the operation of the car.

TABLE I—TEST DATA

No. Test	Motors	Line Amperes	Control Position	Amperes per Motor 1	2	3	4
1	All motors cut in	212	Full parallel	53	53	53	53
2	All motors cut in (Brushes out of No. 3)	96	Full series	96	48	0	48
3	All motors cut in (Brushes out of No. 3)	192	Full parallel	64	64	0	64
4	No. 1 and No. 3 cut out No. 2 and No. 4 cut in	160	Full series*	0	80	0	80

*Note that the full series position on the controller places No. 2 and No. 4 motors in parallel across the line voltage when No. 1 and No. 3 motors are cut out.

The overload conditions on a car in service might be very much worse than that shown by test car, due to any of the following conditions:—

1—Increased car weight due to passenger load.

2—Heavier grades encountered on other parts of system.

3—Reduced trolley voltage.

4—Rapid notching up of control and rough handling of car by careless and indifferent motormen.

5—Possibility of defective or tight brakes.

The results of this test indicated that one motor could be open-circuited, due to a broken or burned off cable lead, and the car could be operated with the motors in this unbalanced condition without the knowledge of the motorman, which would result in overheating the windings of the running mate of the motor with the open circuit.

Short time overload capacity of light and heavy weight motors

The reason why this trouble is more intimately associated with the light weight ventilated motor will be better understood after some thought has been given to the following:—

1—The short time overload capacity of a motor depends upon the available mass of metal in the motor to absorb the heat generated, by the heavier currents in the windings resulting from a temporary overload.

2—The older and heavier non-ventilated type of motor rated at 40 hp, with a continuous current rating of 35 amperes, weighs 2400 lbs.

3—The modern, light weight, ventilated type of motor rated at 40 hp, with a continuous current, rating of 35 amperes, weighs 1500 lbs.

4—Before the general use of ventilated motors, the application of motors to car equipment was made on a basis of the root mean square current required to meet the service conditions; and this current is represented by the continuous rating of the motor.

Conclusion—Hence, with the older and heavier type of motor on the car there was a sufficient mass of metal available to absorb the heat resulting from the short time overloading of the motor, due to the unbalanced conditions resulting from a broken or burned off motor lead and consequently armatures were not as apt to be roasted. On the other hand, the light weight, ventilated type of motor, weighing 62 per cent of the old, heavy type motor, and operating under the same service conditions, is unable to absorb the additional heat due to the short time overload, and its temperature rises rapidly, resulting in roasted armature windings.

PRECAUTIONS SUGGESTED

1—Provide suitable cleats to hold the leads securely to the outside of the motor frame, as suggested in Railway Operating Data for April, 1920.

2—Provide suitable cleats to hold the leads securely to the car body.

3—Hang the leads so that under all conditions of operation they will swing free, to avoid chafing and rubbing.

4—Reinforce the leads with a protective armor.

5—One operating company has provided individual fuses in each motor circuit, to guard against excessive overloads.

6—Change the system of maintenance, to provide for a daily inspection of motor cable leads.

John S. Dean.

THE JOURNAL QUESTION BOX

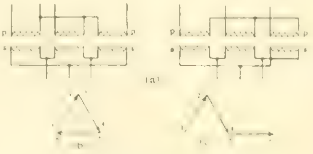
Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

To receive prompt attention a self-addressed, stamped envelope should accompany each query. All data necessary for a complete understanding of the problem should be furnished. A personal reply is mailed to each questioner as soon as the necessary information is available; however, as each queston is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply.

1875—Transformer Connections—We have three single-phase transformers connected as shown in Fig. (a), the primaries in star and the secondaries in delta, one transformer being reversed on either primary or secondary side. Please discuss by means of a vector diagram the voltages across each transformer, and state if it is possible to obtain balanced secondary voltages if the sum of the induced secondary voltages is other than zero. We encountered difficulties with this connection. Two transformers were of additive polarity and the other of subtractive polarity.

S.C. (QUE.)

A single trial will show that is is not feasible to operate transformers in delta when the sum of the induced secondary voltages is other than zero. This is illustrated vectorially in Figs. (b) and (c). Fig. (b) shows the normal voltage connection which gives zero voltage from *1* to *6*. It is safe to tie leads *1* and *6* together. Fig. (c) shows the same connection with phase *5*-*6* reversed in polarity, giving double normal phase voltage across leads *1* to *6*. It is evident that an attempt to fasten together leads *1* and *6* will produce an unfavorable operating condition. However, where the internal polarity of one transformer is opposite to the other two, the connections in Fig. (a) should be correct, as the reversal of external connections merely neutralizes the effect of the different internal polarities.



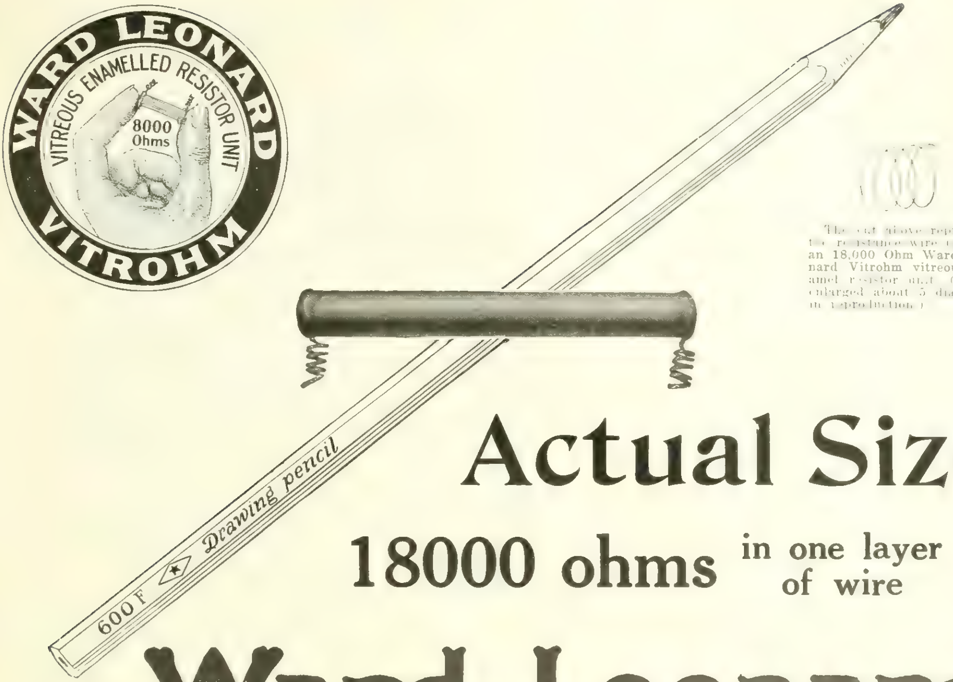
FIGS. 1875(a), (b) and (c)

C.R.R.

1876—Split Core Current Transformers—Is it possible to take fairly accurate power-factor measurements using a split or cable testing type of current transformer in conjunction with the potential transformers and power-factor indicator? D.C. (WYO.)

Split-type current transformers have a large phase angle as compared with other types of current transformers, but they should in general give sufficient accuracy for ordinary measurements with power-factor meters. Their phase angle is not sufficiently small to give accurate results when used with wattless factor meters, where the wattless factor is small

J.F.P.



The cut above represents the resistance wire used on an 18,000 Ohm Ward Leonard Vitrohm vitreous enamel resistor unit. (Object enlarged about 5 diameters in reproduction.)

Actual Size

18000 ohms in one layer of wire

Ward Leonard

Resistor Unit with Vitreous Enameled Insulation

The only reason that such fine wire will live is because it is protected from atmospheric conditions.

The proof that Ward Leonard Vitrohm, Vitreous Enamel does protect from atmospheric conditions is that these units do live and give as good satisfaction as low ohm units which are made of heavier wire.

The proof that there is no equivalent to Ward Leonard Vitrohm, Vitreous Enamel and Ward Leonard manufacturing processes is shown because no one else ever made such a unit of these ohms in this space in one layer of wire.

All Ward Leonard units of whatever ohms or capacity are protected by Ward Leonard Vitrohm, Vitreous Enamel. The proof is sufficient that these units are protected, will live, are the best to use, are the lightest in weight, and the smallest in size. Get a free sample.

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Electric Material Co., San Francisco
Walter P. Ambos Co., Cleveland
Electrical Specialties Co., Detroit
Lyman C. Reed, New Orleans

NATIONAL SAFETY SECTION

BELTS AND BELT GUARDS

Continued

RIVETS

These connections offer the possibility of ragged ends on the opened rivet.

LINK FASTENERS

Certain forms of this type avoid the need of clinching, but they are seldom suitable for better-class use. They are difficult to align and present open joints that may easily catch a garment.

GUARDS FOR OVERHEAD BELTS

High Transmission—Any portion of an overhead belt which is 7 feet or less from the floor, or which must be approached while in motion, should be guarded on the sides and bottom. Heavy or fast-running belts more than 7 feet above the floor, so located that, should they break, they would endanger persons below, should be guarded underneath. As to what constitutes a heavy or a fast-running belt opinions vary; some engineers believe that if a belt located as above is 6 inches or more in width and the speed is 30 feet or more per second, the belt should be guarded. The state of New Jersey requires that belts 6 inches or more in width, so located that breakage would endanger persons below, shall be guarded underneath and that the guards shall extend to the wall or ceiling in such a manner as to retain the belt should it break. The State of Pennsylvania has a similar rule, but places the width of the belt at 10 inches or more. The State of Massachusetts requires that overhead belts 12 inches or more in width and running 30 feet or more per second, located over passageway or working places shall be guarded. Such guards usually are constructed with frames and braces of rolled shapes, with a filler of wire mesh, expanded or perforated metal lattice. It is obvious that the guards should be capable of withstanding not only the weight of the belt, but blows or stresses due to the possible entanglement of the belt. Such guards are usually of the hanging type and should be smooth on the inner surfaces, of a greater width than the belt, and should be brought up around the pulley upon which the belt travels downward, to avoid the broken end whipping around the guard.

GUARDS FOR VERTICAL AND INCLINED BELTS

Low Transmission—All vertical and inclined belts (some authorities except cone-pulley belts and belts 1 inch or less in width) should be so guarded that a hand or other part of the body cannot project through, over, around or under the guard and be caught by a moving part. Authorities are practically unanimous that, if the projection be placed 15 inches or more from any moving part, a height of 3 feet, 6 inches is sufficient for the guard. When the guard is placed less than 15 inches but not less than 6 inches from the thing guarded, the heights recommended vary from 5 to 7 inches, with the majority in favor of a guard 6 feet high, with openings in the filler not greater than 1½ inches. If the clearance is less than 6 inches, then the guard should be 6 feet high with no opening in the filler larger than ½ inches. A guard should not be placed so far from the thing guarded as to invite workmen to get between the guard and the moving parts, or so far as to make it inconvenient to reach bearings, etc., while standing outside the guard. It is recommended that the maximum distance at which a guard be placed from the thing guarded should be 20 inches. The Safety Council advocates the following safe practices as to heights of guards and sizes of openings in the same:—

Distance from Thing Guarded	Height of Guard	Size of Openings
15 to 20 in.	3 ft. 6 in.	
6 to 15 in.	6 ft. 0 ft.	1½ in.
0 to 6 in.	6 ft. 0 in.	½ in

When the upper part of a horizontal belt is less than 6 feet from the floor level the belt may well be guarded over the top, instead of carrying the guard up 6 feet, or a 3 foot 6 inch railing should be placed at least 15 inches and not more than 20 inches horizontally from the edge of the belt.

FLOOR OPENINGS

When belts pass through a floor (or where any guard is placed around a floor opening) a 6 inch solid section or toe-board should be placed at the bottom of the guard to prevent objects rolling or being kicked through the floor opening. Where belts pass through openings in a floor or wall, provision should be made to guard against friction due to the belt rubbing on the edge of the opening. The placing of rollers at the two edges of the belt, so that if the belt rides to one side it will strike the roller and cause less wear and friction, is considered better practice than facing the opening with sheet metal, as is sometimes done.

CONSTRUCTION OF GUARDS

Metal is preferable to wood in the construction of guards. Wooden guards especially if oil soaked, increase the fire hazard; they also are more expensive in upkeep. Metal guards are practically indestructible, wear better and are more substantial. Where guards are subject to acid fumes, wooden guards may be necessary, however. All guards should be of rigid and substantial construction. The railing guards, placed from 15 to 20 inches from the moving parts, should be of the double type, with the top rail 3 ft. 6 inches from the floor and an intermediate rail midway between the top rail and the floor. If constructed of rolled shapes, their section should be at least equal to that of 1½x1½x3/16 inches angle iron. When the railings will be subjected to considerable handling or stresses, 2x2x¼ inch angles, or their equivalent, should be used. If constructed of pipe, they should be not less than 1¼ inch inside diameter. If constructed of wood, the posts should be not less than 2x4 inches, or their equivalent section, and the rails not less than 7/8x6 inches, or theirequivalent section. Uprights in all instances should be spaced not more than 8 feet centers. Preference is given to railings constructed of rolled shapes, as they are less likely to fail. The use of wood should be avoided where practicable. Guards consisting of frame work, with mesh or plate filling, will vary as to strength of material used according to the area of the guard. If the guard is 6 ft. in height and fastened to the floor without other support or bracing, the metal frame of the guard should have a section at least equal to that of 1¼x1¼x1/8 inch angle iron. The filling material is usually attached to an angle frame by means of ¾x1/8 inch flats, fastened to the angle by 3/16 inch bolts or rivets, spaced not more than 10 inch centers, or by 1x1 inch wooden strips fastened to angle by 3/16 inch bolts. Peforated or sheet metal should be bolted or riveted directly to the angle, or spot welded. For a pipe frame a 1¼ inch open seam tube is recommended with the filler clamped in the seam of the tubing.

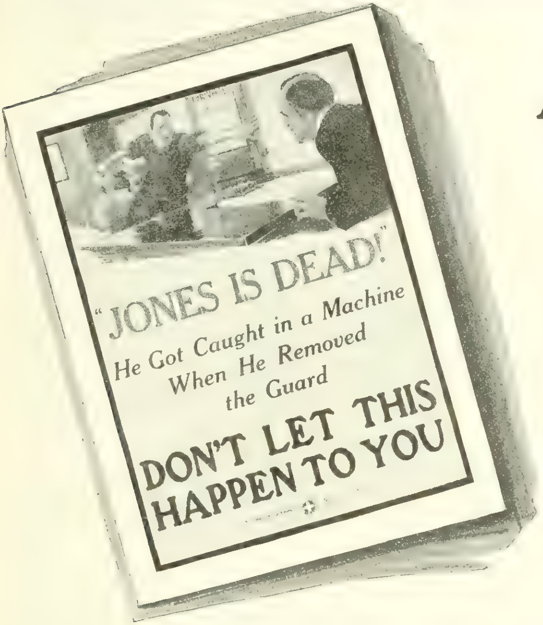
When the dimensions of the guard are not more than 3 feet, or where it is braced every 3 feet, the frame should be equivalent in strength to ¾x¾x⅛ inch angle iron, or ¾ inch open seam tubing.

FILLER

Filling material should not have openings larger than ½ inch when the guard is placed within 6 inches of a moving part, nor larger than 2 inch (1½ inch recommended) when more than 6 inch and less than 15 inches from the moving part. When the area of the guard between braces is 4x4 feet it is recommended that wire mesh be at least No. 12 U. S. gauge, 1½ inch mesh or perforated or sheet metal of at least No. 14 gauge but 10 gauge is recommended. No. 16 gauge, perforated or sheet metal, will make a substantial filler when the area between stiffeners does not exceed 3x3 feet. The filler used for smaller areas may be of smaller gauge metal, but a gauge smaller than 18 should not be used because lighter weight guards have a short life. All guards should be substantially fastened in place, and, where it is necessary to have access to machinery, portions of the guard should be arranged to swing or slide. All sharp edges of filler should be protected and where hand holes are provided the edges should be reinforced by at least No. 24 gauge sheet metal, but No. 18 gauge is recommended. When a gate or door is required, it is recommended that the frame be at least equal to 1x⅝x⅛ inch angle, and that means be provided to hold it securely in place.

DESIGN OF GUARDS

Care should be exercised in the design of guards to provide convenient access to parts which must be repaired or maintained. This may be done by making the guards movable or by providing doors or removable panels.



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PASADENA N. E. L. A. CONVENTION PROGRAM

The following program for the general, technical, hydro-electric and commercial sections, has been announced for the 43rd convention of the National Electric Light Association to be held at Pasadena, California, May 18-22, 1920. In addition to the usual technical and commercial meetings an elaborate entertainment program has been prepared. Three special trains are to be provided for the convenience of visiting delegations in the East, information regarding which can be secured at the national headquarters at 29 West 39th St., New York City.

FIRST GENERAL SESSION

Wednesday, May 19th, 9:30 A. M.

1—"Welcome to California"—Hon. William D. Stephens, Governor.

2—Address of President—R. H. Ballard.

3—Committee on President's Address.

4—Report of Executive Manager, M. H. Aylesworth.

5 Announcements.

6—Report of Committee on Water Power Development. Franklin T. Griffith, Chairman.

7—Report of Committee on Rate Research. Alex Dow, Chairman.

8—Report of Lamp Committee. Frank W. Smith, Chairman.

9—Report of Insurance Expert. W. H. Blood, Jr.

10—Address by John G. Learned, Chairman of Commercial Section.

11—Report by J. Paul Clayton, Chairman, Merchandise Sales Bureau.

SECOND GENERAL SESSION

Thursday, May 20th, 9:00 A. M.

1—Committee Report on Company Sections—F. A. Birch, Chairman.

2—Committee Report on Geographic Sections—R. J. McClelland, Chairman.

3-4—Addresses. Speakers and subjects to be announced.

5 Election.

6—Report of Committee on Constitution and By-Laws—W. C. L. Eglin, Chairman.

7—Appointment of Committee on Memorials.

8—Appointment of Committee on Resolutions.

9—Report of Bureau on Advertising and Publicity Service—L. D. Gibbs, Chairman.

10—Paper of Committee on Service—S. M. Kennedy, Chairman.

11—Report of Committee on Membership—Walter Neumuller, Chairman.

12—Report of Treasurer—H. C. Abell.

13—Address by E. O. Edgerton. (Title to be announced)

THIRD GENERAL SESSION

Friday, May 21st, 9:00 A. M.

1—Address by Chairman of Accounting Section—R. W. Symes.

2—Report of Committee on Education—Fred R. Jenkins, Chairman.

3—Report of Committee on Accounting Education—Douglass Burnett, Chairman.

4—Report of Committee on Relations with Educational Institutions—John F. Gilchrist, Chairman.

5—Report of Committee on Accident Prevention—Chas. B. Scott, Chairman.

6—Report of Committee on Safety Rules.

7—Address by I. E. Moultrop, Chairman, Technical and Hydro-Electric Section.

8—Report of Committee on Inductive Interference—A. E. Silver, Chairman.

9—Report of Committee on Electrification of Steam Railroads—Frank M. Kerr, Chairman.

10—Report of Committee on Commercial Service and Relations with Customers—R. F. Bonsall, Chairman.

11—Paper by Carl D. Jackson on "Trend of Regulation."

12—Report of Committee on Electrical Resources of the Nation—M. S. Sloan, Chairman.

FOURTH GENERAL SESSION

Saturday, May 22nd, 9:00 A. M.

1—Address by George B. Foster, Chairman, Electric Vehicle Section.

2—Paper by Zenas W. Carter, Secretary, Material Handling Machine Mfg. Association, New York, on "Electric Machinery for All Handling."

3 Report of Committee on Public Information—John F. Gilchrist, Chairman.

4—Report of Committee on Bonus Systems—Harry A. Snow, Chairman.

5—Report of Committee on Insurance—E. J. Fowler, Chairman.

6—Report of Committee on Co-operation in the Industry—Lee H. Newbert, Chairman.

7—Address by J. M. Wakeman, General Manager, on "The Work of the Society for Electrical Development, Inc."

8—Report of Committee on Sale of Company Securities to Customers and Resident Citizens—George R. Jones, Chairman

9—Report of Committee on Doherty and Billings Prizes—A. S. Loizeaux, Chairman.

COMMERCIAL SECTION

Wednesday, May 19th, 2:30 P. M.

1—Address of Section Chairman, John G. Learned.

2—Report of Committee on Finance—M. S. Seelman, Chairman.

3—Appointment of Nominating Committee.

4—Report of Committee on Constitutional Amendments—R. H. Tillman, Chairman.

5—Report of Committee on Wiring—R. S. Hale, Chairman.

6—Report of Bureau of Merchandise Sales—E. A. Edkins, Chairman.

7—Report of Division on Electrical Merchandise—F. D. Pembleton, Chairman.

8—Report of Division on Electric Shop Management—C. E. Greenwood, Chairman.

9—Report of Division on Standardization and Testing—O. R. Hogue, Chairman.

10—Report of Division on Electric Ranges—J. Paul Clayton, Chairman.

Thursday, May 20th, 2:30 P. M.

1—Report of Committee on Electrical Salesman's Handbook—I. Lundgaard, Chairman.

2—Report of Division on (Power Sales Bureau) Economics of the Use of Central Station Electric Power—John W. Meyer, Chairman.

3—Report of Division on (Power Sales Bureau) Electro-Chemical Processes—C. H. McClure, Chairman.

4 Report of Division on (Power Sales Bureau) Industrial Electric Heating—N. T. Wilcox, Chairman.

5—Report of Bureau on Lighting Sales—Clarence L. Law, Chairman.

6—Report of Division on Street and Highway Lighting—W. T. Dempsey, Chairman.

7—Report of Division on Residence Lighting—M. Luckiesh, Chairman.

8—Report of Division on Commercial Aspects of Lamp Equipment—George H. Stickney, Chairman.

Friday, May 21st, 2:30 P. M.

1—Report of Committee on Compensation of Salesmen—Adolph Hertz, Chairman.

2—Election of Officers and Executive Committee.

3 Report of Division of (Power Sales Bureau) Electric Steel Furnaces—Joseph McKinley, Chairman.

4—Report of Division of (Power Sales Bureau) on General Power—W. E. Murphy, Chairman.

5—Report of Division of (Power Sales Bureau) Power Contracts—R. H. Ashworth, Chairman.

6—Report of Division (Power Sales Bureau) on Isolated Plants—J. B. Stuart, Chairman.

7—Report of Division (Power Sales Bureau) on Electric Development—Morse Dell Plain, Chairman.

ELECTRIC VEHICLE SECTION

Friday, May 21st, 2:30 P. M.

1—Address of Section Chairman—George B. Foster.

2—Appointment of Nominating Committee.

3—Report of Committee on Garage and Rates—Willis M. Thayer, Chairman.

4—Report of Committee on Legislation—G. A. Freeman, Chairman.

5—Paper on "The Uses and Abuses of Electric Vehicles"—H. T. Butler and W. J. Burns.

6—Report of Committee on Electric Vehicle and Power Sales Bureau Co-operation—E. S. Mansfield, Chairman.

7—Report of Committee on Transportation Engineering—F. M. Feiker, Chairman.

8—Paper on "The Electric Truck Industry"—C. A. Street, Walker Vehicle Company, Chicago.

9—Report of Committee on Federal and Municipal Transportation—James H. McGraw, Chairman.

TECHNICAL AND HYDRO-ELECTRIC SECTIONS

Wednesday, May 19th, 2:30 P. M.

1 Address by Section Chairman—I. E. Moultrop.

2—Appointment of Nominating Committee.

3—Report of Committee on Meters—F. V. Magalhaes, Chairman.

4—Report of Committee on Prime Movers—N. A. Carle, Chairman.

Thursday, May 20th, 2:30 P. M.

1—Election of Officers and Executive Committee.

2—Report of Committee on Overhead Systems—W. K. Vanderpoel, Chairman.

3—Report of Committee on Underground Systems—F. E. Ricketts, Chairman.

4—Report of Committee on Electrical Apparatus—R. F. Schuchardt, Chairman.

A. E. R. A.—1920 CONVENTION

The American Electric Railway Association has announced that their next annual convention will be held at Atlantic City, New Jersey, October 11-15.

PERSONALS

Mr. H. D. Shute, vice-president of the Westinghouse Electric & Mfg. Company, has been elected a member of the board of directors of the West Virginia Metal Products Company of Fairmont, W. Va.

Mr. W. E. Thau of the general engineering department of the Westinghouse Electric & Mfg. Company, has recently been appointed engineer in charge of the marine engineering section of the Company.

Mr. L. B. Stillwell, consulting engineer and formerly president of the American Institute of Electrical Engineers, has been elected a life member of the board of trustees of Princeton University.

Mr. H. H. Bates, field engineer in the stoker department of the Westinghouse Electric & Mfg. Company, has resigned to accept the position of superintendent of equipment of the Acme White Lead & Color Works of Detroit, Michigan.

Mr. Brent Wiley has been appointed assistant to Manager of the industrial department of the Westinghouse Electric & Mfg. Company at East Pittsburgh to be in general charge of electrical applications in the mill industries.

Mr. J. C. Jones, manager of the Salt Lake City office of the Westinghouse Electric & Mfg. Company, has been appointed manager of the supply division of the Los Angeles district office.

Mr. Bernard Lester of the industrial sales department of the Westinghouse Electric & Mfg. Company has been appointed assistant to the manager of this department to have general charge of small motor and merchandising activities.

Mr. Robert M. Searle, vice-president of the Rochester Railway & Light Company, has been elected president of this Company to succeed James T. Hutchings, who resigned recently to become assistant general manager of the United Gas Improvement Company of Philadelphia.

Mr. G. E. Stoltz, of the general engineering department of the Westinghouse Electric & Mfg. Company, East Pittsburgh, has been appointed engineer in charge of the steel mill section. Mr. Stoltz has been with the Company since 1909.

Mr. L. A. S. Wood, who has been prominent in illuminating engineer work both in this country and Europe, having specialized on the utilization of both flame carbon and Mazda lamps during the past nine years, has recently been appointed manager of the illuminating section of the Westinghouse Electric & Mfg. Company, with headquarters at South Bend, Ind.

NEW BOOKS

"Capitol Today"—Herman Cahn. Size 6 by 9 inches. 271 pages. Published by G. P. Putnam's Sons, New York City. Price $2.00.

While the great majority are in earnest pursuit of something more than mere livelihood and that is a competency, which may be likened unto a large reservoir from which they may draw in the future. When considerable wealth has been amassed, which may appear in the form of property, securities, bank deposits, actual money or money tokens, it should become a matter of immediate interest to know how value is measured and created. This book is a revised and enlarged edition of the first contribution of the writer on the above subject. The author shows that wealth, under our present economic situation, is largely an accumulation of profits and labor and considerable attention has been given in this book to the Marxian Theory of value. Much interesting information is presented and quite a different viewpoint is developed from that of most economists. The efforts of the author provide an unusual and unique treatment from the angle from which he approaches the subject. E.D.D.

"The Earning Power of Railroads"—Compiled and edited by Floyd W. Mundy. 270 pages—five by seven inches. Published by Jas. H. Oliphant, New York City. Price $2.00.

This book contains analyses of earnings and expenses of the steam railroads of the United States, together with mileage and other data indicative of the extent of the road and its operation. Outstanding securities, both stock and bonds are included. The capitalization and expenses are reduced to a basis of per mile of road for comparative purposes. Income accounts are given in detail for 1917 and comparative earnings and expenses are shown as far back as 1908. The author presents a discussion of the important sub-accounts under operating expenses and proves that the same costs per mile of road for the different items of expenses for two roads under comparison are not indicative of a like degree of conservatism. The ton-miles and passengers carried and the general nature of operations generally must be considered. This volume is published annually and presents information which is much sought after by investors in railroad securities and students of railway operations.

"Principles of Direct-Current Machines"—Alexander S. Langsdorf. 460 pages, 314 illustrations. Published by McGraw-Hill Book Co. Price $4.00.

This is the second edition of this work originally brought out in 1915. The present work embodies suggestions based on criticisms on the previous edition and includes certain alterations and new material which experience has shown to be desirable. Where the original symbols did not conform to A.I.E.E. standards, corrections have been made. The author states that the fundamental idea of the book is to present the subject in such a manner as to satisfy the student who wants to know *why* rather than merely *how* things are done. A general idea of the contents may be judged from the chapter headings which are:—General Laws and Definitions, The Dynamo, Armature Windings, The Magnetization Curve—Magnetic Leakage, Armature Reaction, Operating Characteristics of Generators, Motors, Commutation, Compensation of Armature Reaction and Improvement of Commutation, Efficiency, Rating & Heating, Boosters and Balancers, Train Lighting Systems.

"Governors and The Governing of
Prime Movers" W. Trinks. 236 pages
Prime Movers"—W. Trinks. 236 pages, 140 illustrations. Published by D. Van Nostrand Co. New York City. Price $3.50.

So many books try to cover a large field that it is refreshing to review a book claiming to cover only one detail of a given subject. In the present case the so called detail is a subject of sufficient importance to warrant the very thorough attention of experts such as the author who has specialized largely on this subject. Previous publications have taken up governors in connection with steam engines or water turbines but with few exceptions the investigations and explanations have not gone very deeply into the subject. The present volume is a book of essentials and principles. No commercial forms are shown but the drawings have been apparently made especially for the purpose and show the principles and details involved. Relay governing is discussed including such types as are used on steam turbines. An elaborate bibliography is included, also a bookmark list of symbols used in the book.

"Elements of Radiotelegraphy—Ellery W. Stone. 267 pages, 125 illustrations, 33 plates. Published by D. Van Nostrand & Co., New York City. Price $2.50.

This book was written primarily for students in the communication service of the United States Navy. The subject as presented from the physical rather than the mathematical standpoint and as a resume of a series of lectures given at the U. S. Naval Radio Station at San Diego, California. In addition to fundamentals, descriptions are given of the various wireless systems available with discussion on antennae and earth connections. Naturally the discussions are intended more for operating men than for theorists.

"Applied Mechanics"—Charles E. Fuller and Wm. A. Johnston. 566 pages, 282 illustrations. Published by John Wiley & Sons, New York City. Price, $3.75.

This is Volume II on "Strength of Materials" prepared primarily for the use of students at the Massachusetts Institute of Technology. Graphical methods and calculus have been employed throughout and it is assumed that the student has a knowledge of statics and dynamics. Chapters are devoted to continuous beams, columns, shafting and springs, arches, cylinders, reinforced concrete beams and columns. Numerous problems are interspersed throughout the text.

TRADE NOTES

The Page Steel & Wire Company have just published a very complete pamphlet describing fully the electrical and physical properties of American Ingot Iron Wire. This is the first complete publication of this data and the result of many tests made during the past two years under the supervision of the Electrical Testing Laboratory, New York, and Frank F. Fowle, Consulting Electrical Engineer for this Company. This booklet is very interesting and will be mailed to any one desiring copy upon request to Page Steel & Wire Company, 30 Church St., New York.

Luminous Unit Co., St. Louis, Mo., have just issued their Catalog No. 7, illustrating and describing their "Brascolite" line of lighting units in various designs, also their industrial fixtures, also their glass or "Aglite Fixtures," the latter being of particularly novel design. They are used particularly in bath rooms, hospitals and wherever white glass would be suitable.

Benjamin Electric Mfg. Co., Chicago, Ill., have published their Bulletin No. 18 entitled "Better Electric Lighting on the Farm," which describes and illustrates various forms of reflectors, lamp socket fixtures, plugs and other fittings for use in connection with farm lighting outfits. A copy of this publication will be sent by the Company on request.

NEW DEVELOPMENT IN SUSPENSION TYPE INSULATORS

The suspension type of insulator has become generally standardized for use in high tension transmission work. About ten years ago Mr. E. M. Hewlett invented the link type insulator but this type has not come into very general use. This was due largely to the inpracticable hardware detail parts then available. Three years ago the engineering staff of the R. Thomas & Sons Co., East Liverpool, Ohio, began the development of fittings suitable for general commercial use. Numerous designs were made and tested, but it was not until a little over a year ago that what was considered a satisfactory design was invented. The new design which is here illustrated has been given thorough laboratory tests and thousands of units have been tried out on transmission lines where the product would be given severe operating service. In its present form the changes claimed for this new design are:—

1—The porcelain is thrown in absolute compression having no side pull nor lengthy porcelain walls in tension.

2—The entire surface of the insulator is thoroughly glazed.

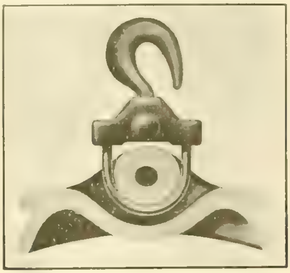
3—Due to the flexible construction of the parts there are no concentrated stresses imposed on the porcelain but an even distribution of the load.

4—There is no cement composition or alloy required in the assembly of units.

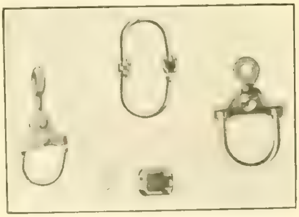
5—Strings of insulators may be assembled and made up in the field as easily as in the factory.

6—The ultimate cost for transmission line construction is greatly reduced by the long life of the insulator and the salvaging of connecting parts.

The material in contact with the porcelain surface is a relatively soft metal, such as copper, so that there is no crushing or injury to the glaze on the insulator. This new design is suitable for transmission work and for "dead ends" where the strings of insulators are in a horizontal position. Reports from a considerable number of power companies indicate perfect satisfaction with this newly developed insulator. On one line in Colorado, 183 miles in length, the entire dependence for insulators is placed on this new insulator. The R. Thomas & Sons Company have service records from the various companies who have tried out this design and will be glad to give reports on these installations to any who are interested, along with prints and photographs showing the details of the design, and also views of insulators in service in various parts of the country.



SECTIONAL VIEW OF NEW INSULATOR



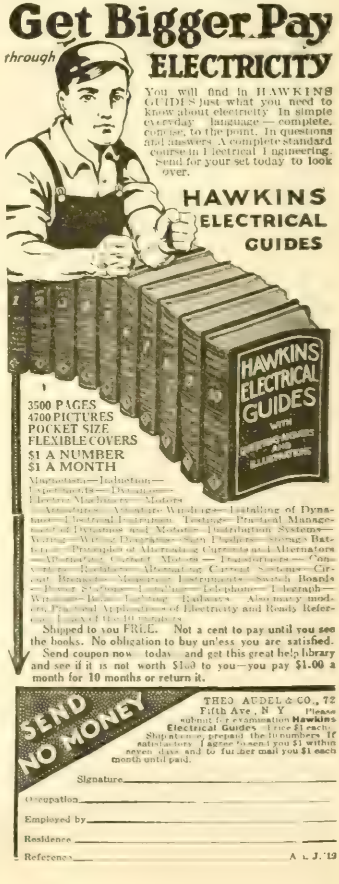
DETAIL PARTS OF NEW INSULATOR

MONARCH REFILLABLE FUSES

The Monarch Refillable Fuse Company of Jamestown, N. Y., have placed a new renewable fuse on the market in both ferrule and knife blade types. The knife blade type has heavy brass inner sleeves, threaded and riveted into the inside of the fibre tube at both ends. Attached to the inner sleeve are heavy brass bridge pieces. These swinging bridge pieces interlock into the knife blades, thus automatically aligning the knife blades and preventing endwise movement. As the swinging bridge pieces are attached to the brass inner ferrules, loose parts are eliminated and brass washers spun into the outer ferrule also eliminate loose washers. The renewal link can be slipped into position after loosening the nuts on the knife blades without complete removal of nuts. The ferrule type also has heavy brass inner sleeves threaded into and riveted to the inside ends of the fibre tube. Machined washers, through which the renewal link is threaded and turned over and machined outer ferrules screwed down onto threads on the brass inner sleeves give perfect contact and alignment. On both types the metal-to-metal thread eliminates the trouble of charring of fibre threads and loosening of ferrules from fibre contraction. The construction also eliminates troublesome loose parts and the fuses are easily renewed and strongly constructed.

The Delta-Star Electric Company of Chicago have recently issued their special publication number 92 of their unit type high tension outdoor substations.

The Standard Underground Cable Company, Pittsburgh, Pa., have issued their bulletin No. 500-1, describing their standard rubber insulated wire including a wide variety of sizes for all classes of service. This is the line which is identified by their trade mark of green thread or strand woven into the braid.



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THE ELECTRIC JOURNAL

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Some Figures Electrical

One of the incidental results of war activities has been a more intimate acquaintance by the general public with large figures—there were billions in Liberty loans and millions of soldiers. Everything in a military way was carried on in a manner involving unprecedented figures. Whether or not the average person has secured any clearer conception of the meaning of such large figures may be open to question. Engineers, however, are trained in the use of statistics and should have a better understanding of their significance.

During the past year the National Electric Light Association has had several committees at work which have made at least a beginning in the assembling of statistical information of value to the electrical industry. One of the most important of the newer committees is that on the electrical resources of the nation. It is hoped that through the activities of this committee there will be produced a continuous census of the important facts related to the power industry. In their report at the Pasadena convention last month, advance figures were given from the forthcoming census report for the year 1917. During that year over twenty-five billion kilowatt-hours of electrical energy were produced in 6542 central stations, having a combined generating capacity of nine million kilowatts, which was sold for a little over five hundred million dollars to more than seven and one-half million customers. It is interesting to note that this represents an average generating capacity of 1378 kilowatts per station, with an average load factor of 31.7 percent based on installed capacity, and that an average of 278 kilowatt-hours per month was used by each customer. It emphasizes the fact, which is liable to be overlooked, that the great majority of central stations in the United States are still of quite limited size. It is estimated by the committee that the total generating capacity of the country at present is nearly eleven million kilowatts and that the output during 1919 was thirty-three billion kilowatt-hours. None of the above data includes electric railway power plants.

The committee also gives figures as to what may be called the latent sources of power, or the raw materials from which electricity is generated. These are estimated at fifty-four million horse-power in water power and three billion tons of coal. Under normal conditions the installed capacity for power generation has doubled in periods of five years. Since 1917 this rate has not been maintained and this fact forms one of the unsatisfactory conditions in the central station industry today, as there is no doubt but that several million additional kilowatts in capacity could be utilized if it could be made available in the next year or so. President Ballard stated in his annual address that "the industry needs seven hundred and fifty million dollars of new capital right now" to take care of the requirements of the country.

The Electric Furnace Committee announces that during 1918 three hundred million kilowatt-hours were used in producing steel in electric furnaces, since which time there have been installed thirty-six additional steel furnaces, so that by the beginning of 1920 there were 323 electric steel furnace installations. This is in addition to electric furnaces for the production of non-ferrous alloys, carbide and other products, for which large blocks of power are required. The committee on electric heating states that the use of electric furnaces would go a long way toward eliminating the present loss of metal, through volatilization and oxidation in fuel fired furnaces, of some six hundred million pounds of metal annually. If electric furnaces were used exclusively, the metal saving alone would more than pay for the current used, figured at one and one-half cents per kilowatt-hour.

In the incandescent lamp field, a production is indicated of one hundred and eighty-three million lamps last year, exclusive of miniature lamps, and of this total production, over 90 percent was in the form of tungsten filament lamps. During 1919 the total production of tungsten filament lamps in candle-power was over nine times that of all lamps sold in 1907. During the same period the average candle-power of incandescent lamps has increased from 18 to 53 candle-power. It is worth noting also, in these days of almost universal price increases, that tungsten lamps, of the 40 watt size for example, that sold in 1907 for $1.50, are in 1920 sold around 38 cents.

The committee on material handling quotes figures to show that the railroads of the country might save four hundred million dollars per year in handling charges if suitable electrically operated handling machinery were installed at terminals. The statement is made that there is a potential annual demand for over five hundred million kilowatt-hours for power service on this account.

Authentic information of the character mentioned above, carefully revised annually, should be of great value to those in the electrical industry, both for their own information and as a means of securing the cooperation of governmental departments and public service commissions in the future development of the power industry along lines which will be of greatest value to the Nation as a whole.

Charles Wood Johnson

An Appreciation

Chas. F. Scott

THERE was something about C. W. Johnson which at once gave an impression of bigness; bigness of heart and bigness of purpose; he was physically large, with a deep full voice, with a large hand which gave a cordial, hearty handshake. There was withal the feeling that your new acquaintance, or your old friend, whichever he happened to be, was genuine, sympathetic and earnest. As one knew him better and longer, this openness and freedom of manner proved to be the natural expression of the character and the mind of the man himself. His interest was in the fundamental, under-lying things. His plan was not to temporize and use mere expediency for getting immediate results. He wanted to go to the bottom of things and deal with sound principles and get things established on a fair and true basis. He was open minded, and ready to accept results of argument and reason.

Mr. Johnson took a deep interest in the relations between the workmen and the Company. He sought to determine a fair basis and his aim was to get a mutual understanding. He saw that often the minor officials in the shop did not have a correct attitude toward the men under them and were misinterpreting the policy of the management of the Company, and at one time his particular duty was to undertake personally to establish more cordial relations by a better understanding.

C. W. Johnson

In a talk with me about a year ago he deplored the misunderstanding and misstatements of many outside people interested in industrial affairs and welfare work who seemed to take it for granted that in industry the management was always seeking to take advantage of the workmen and was not trying to establish relations on a fair and equitable basis. I remarked, "Why, Mr. Johnson you are simply assuming that all corporations are like the one you represent and that they have this broad view." He retorted, "There you are, proving my contention; you, yourself are taking the ground that most corporations are not considering the welfare of their men in a broad way. I contend that the desire of managers in general is to do the right, fair and human thing in relation to their employees."

When one occasionally meets his old acquaintances, the inherent qualities are apt to appear. In talking with Mr. Johnson, there was at once the characteristic vision, optimism and earnestness. His aim was to overcome the difficulties; to lay a sound basis for progress. He looked at things in a large way. He progressed from one position to another toward larger responsibilities and new opportunities.

It was his fine purpose, his high ideals, his noble character, his vision, his integrity, his earnestness, his frankness and his cordiality of manner that gave him the respect of his fellows and gained the confidence which endeared him to them.

Years ago he wrote in The Electric Journal a "Suggestion to Engineering Apprentices" in which he says "The motto of the apprentice should be 'to learn a few things well and in all their detail'. A man's value is measured, not by the things of which he has a smattering knowledge but by those things which he has mastered."

Mr. Johnson's career from university to assistant director of engineering in a large industry is significant. From one position to another, not by a prearranged plan, but by making good each opportunity as it arose, he advanced through various departments, through shop work and drafting room and engineering, through manufacturing and personnel again to engineering and administrative, gaining in experience, broadening in sympathy and outlook, preparing himself for new duties—more comprehensive and more intricate and more responsible.

About twenty years ago in the Bullock Company at Cincinnati, Mr. Johnson was associated with Mr. B. A. Behrend who writes me this paragraph:—

"Charlie was a Quaker. He believed in the kindliness and good fellowship of the Society of Friends and he was always deeply interested in that which really made up and constituted religion. I remember well that David Hall, William Cooper, Charles Johnson and I would occasionally come together and I had the pleasure of reading to them chapters from the Bible, which we all enjoyed. Johnson had great skill in handling men, and he was always well liked by everybody. He was very much in earnest in all that he did, and he could always be relied upon to do something for his friends or for people who made an appeal to him".

After graduating at Ohio State University as an electrical engineer in 1896, Mr. Johnson began work in the drafting department of the Steel Motor Company of Johnstown, Pa., where he was associated with Mr. Merrick who was later the general superintendent of the Canadian Westinghouse Company at Hamilton. In May 1897, he took a position as draftsman with the Bullock Electric Mfg. Company of Cincinnati, Ohio. Here he advanced to chief draftsman, engineer and production manager in a period of six and one-half years. In February 1904 he was transferred to Montreal, Canada, and made manager of the electrical department of the Canadian Bullock Electric Mfg. Company, Ltd., (later Allis-Chalmers-Bullock, Ltd.) where he remained until 1907, when he joined the Westinghouse Electric & Mfg. Company at East Pittsburgh and was soon appointed chief inspector. In January 1910 he was appointed assistant manager of works. In March 1912 he was made general superintendent, a position he held until 1919, when his chief activities were transferred to the industrial relations of the company with its employees. At the time of his death, April 21st, 1920, he was assistant director of engineering in charge of developments.

In 1901 Mr. Johnson married Evelyn Vaughan of Selma, Alabama. He is survived by Mrs. Johnson and a five year old boy, Robert Gray Johnson.

The loss of such a man is all the greater because such men are too few.

The Electrical Equipment and Control

Of the Chicago, Milwaukee & St. Paul Locomotives

P. L. Mardis

THE OPERATION of an electric locomotive is governed by, and depends upon the method and manner of its control. The control equipment, therefore, may very properly determine the sufficiency of the whole locomotive. As the control system comprises a number of separate elements, it is essential that their correct functioning, individually and collectively, shall be assured by careful design and assembly.

FIG. 1—THE "OLYMPIAN" AND "COLUMBIAN" AT THE BUTTE, MONTANA, PASSENGER STATION

In order to insure perfection of detail of the novel features involved in the control system and equipment used on the Chicago, Milwaukee & St. Paul locomotives, an experimental 45 ton locomotive was first built and tested. This locomotive, provided with regenerative braking, was placed in service on the lines of the Monongahela Valley Traction Company in West Virginia. The results of tests on this locomotive data from service operation, and an analysis of the final control system resulted in the improvement of the control scheme in several minor particulars.

Forty-five thousand locomotive miles operation to date, without a delay due to control failure, is in itself evidence of the accurate preliminary work done on the control of these locomotives. The following description conveys some idea of the problems arising in the design of the electrical equipment and the manner in which they were solved.

Before deciding upon the main circuit connections, an analysis was made to determine the motor groupings and speed combinations which would give the most economical operation and be most suitable to the profile of the road, both during motoring and regenerative braking. The total horse-power required and the limitation of weight per driving axle determined the use of six driving axles with six twin-armature motors.

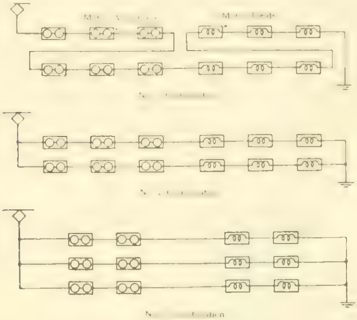
FIG. 2—SERIES-PARALLEL CONNECTIONS FOR MOTORING

MOTORING CONNECTIONS

The consideration of economical acceleration, existing trolley voltage, minimum voltage per commutator and the desired operating speeds, resulted in the selection of three groupings of the main motors, as shown in Table I and Fig. 2. The use of two field shunt notches in each of the three motoring combinations gives a total of nine running speeds, thereby permitting an economical adjustment of speed for varying track conditions, schedules and slow orders.

TABLE I—MOTOR COMBINATIONS

Motor Combination Number	Motor Grouping	Speed	Voltage Per Commutator
1	All six in series	One-third	250
2	Two parallel sets of three motors in series	Two-thirds	500
3	Three parallel sets of two motors in series	Full	750

REGENERATIVE BRAKING CONNECTIONS

During regenerative braking, the current for excitation of the main motor fields is supplied by two axle-driven generators, one being mounted on the inner axle of each engine truck. A stabilizing resistance is connected in the circuit in such a manner that both armature and field current pass through it during regeneration. By reason of this connection, any sudden change in regenerated current reacts on the fields to limit the change in current, thereby assuring stable operation of the series motors, acting as generators during regeneration.

The schematic arrangement of circuits for the three motor combinations during regeneration is given in Fig. 3. The armatures are grouped, in the three combinations, exactly the same as in motoring. The field circuits, however, are broken up to insert the stabilizing resistance and axle-generator armatures.

In the No. 1 combination the 12 armatures, in series, are connected to ground through the stabilizing resistance. To simplify the circuits and switching apparatus, the 12 fields are connected across the stabilizing resistance in two sets of six fields each, with one axle-generator in the circuit of each set supplying the excitation. In the No. 2 combination, the current for each set of six armatures, passes through its own stabilizing resistance, around which are connected the six fields in series with their axle-generator excitation armature. The No. 3 combination requires a parallel connection of the two axle-generator armatures to supply excitation for the three parallel sets of four fields each.

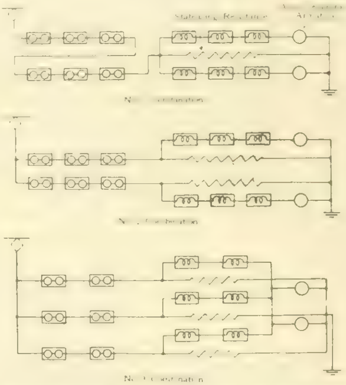

FIG. 3—SERIES-PARALLEL CONNECTIONS FOR REGENERATING

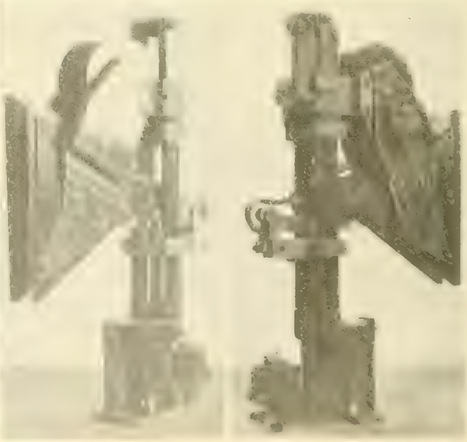
FIG. 4—3000 VOLT ELECTRO-PNEUMATIC SWITCH
With magnetic blow-out and arc splitters.

MAIN CIRCUIT SCHEMATIC

The actual main circuits in schematic form are given in Fig. 8, with the switches required to establish the various motoring and regenerating combinations, and to make the shunting transitions from one combination to another, during acceleration. The sequence diagram, Fig. 9, used in connection with the main circuit schematic, gives in a condensed form the necessary order of closing and opening the switches to set up the different combinations of the main motors.

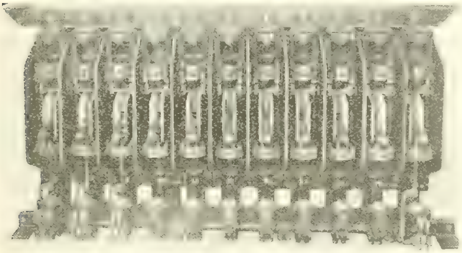

FIG. 5—ELECTROPNEUMATIC SWITCH GROUP

Having decided upon the general scheme of main motor connections, the next consideration was the selection of the proper electrical equipment for making and breaking the 3000 volt circuit to the motors, cutting out resistance and effecting the changes in the motor groupings from one combination to another.

The 3000 Volt Unit Switch—The line switches and resistance switches are subject to the full stress of 3000 volts to ground and are called upon, in normal service to break currents as high as 200 amperes at 3000 volts. They have no fuse or short-circuit protection, other than the substation high-speed circuit breaker. These conditions, obviously, require a switch of great reliability.

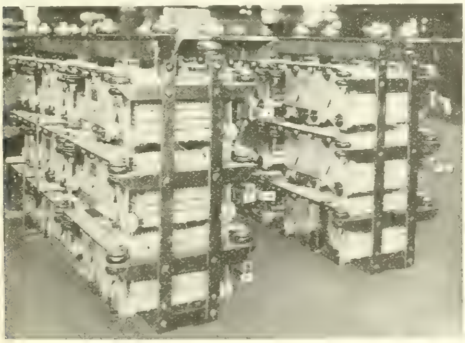

FIG. 6—MAIN GRID RESISTOR ASSEMBLY

In order to test the relative merits of several types of magnetic blow-out switches, four different types of switches were built and tested to destruction. Based on the experience gained in testing these switches, the electropneumatic, magnetic blowout, 3000 volt switch shown in Fig. 4 was built. Being of the unit type, any switch may be removed from a group of switches without disturbing the remainder of the group, Fig. 5.

The use of compressed air at 70 lbs. per sq. in. for operating the switches gives a contact pressure of approximately 100 pounds. The contact is closed by a total force of 200 pounds against a spring pressure of 100 pounds, this spring pressure of 100 pounds being available for opening the contact. These heavy operating forces insure the reliability of the switch by eliminating heating and welding due to poor contact.

Main Grid Resistors—Sixty-two frames of three-point cast-iron grids are used to limit the current in the traction motors during acceleration. In the design and mounting of these resistors, especial attention was given to the insulation of the grids from ground, as they are all subject to 3000 volt stress to ground, when running with resistance cut out.

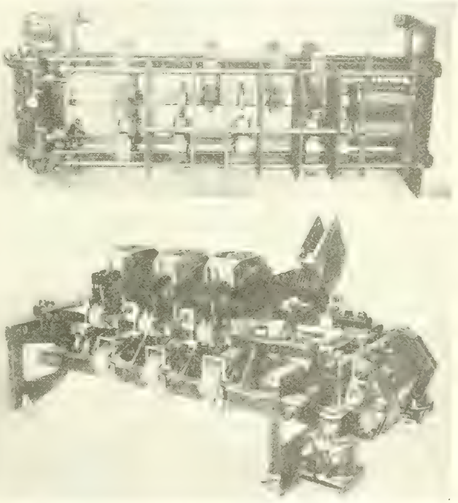

FIG. 7—MOTOR COMBINATION CAM SWITCH GROUP, ALSO CAM SWITCH GROUP WITH MAGNETIC BLOW-OUT

The grids in the individual frames are insulated from the tie-rods with 1200 volt insulation. A group of frames is mounted on a common supporting angle, Fig. 6, and insulated from this angle by special 3000 volt insulators. This supporting angle is, in turn, insulated from ground by 3000 volt insulators. This gives a total insulation sufficient for a normal working stress of 7200 volts, and the effectiveness of this insulation is further increased by reason of its being divided into three sections.

MOTOR COMBINATION SWITCHING APPARATUS

Two groups of electropneumatic, cam-operated switches (Fig. 7) are provided for making the changes in the motor groupings; one for the No. 1 to No. 2 combination change and one for the No. 2 to No. 3

combination change. The use of groups of cam-operated switches for making the transitions, eliminates the possibility of setting up false circuits through faulty transition, simplifies the control wiring and interlocking and requires a minimum of cab space.

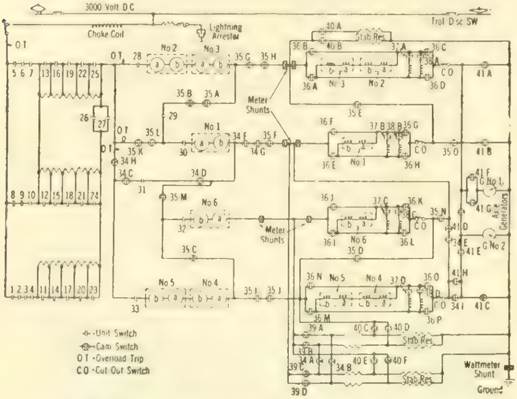

FIG. 8—SCHEMATIC DIAGRAM OF MAIN MOTOR CIRCUITS

The cam group, as shown in Fig. 7, is of skeleton construction, consisting of individual switches mounted on micarta insulated bars, supported between cast-iron end frames. The cam shafts in these cam switch groups are operated through a rack and pinion, by a pair of air cylinders, to which air is admitted and released by magnet operated valves which are energized from the master controller. The method of assembling these groups permits of the removal of any part without disturbing the remainder, and their open construction facilitates inspection and maintenance.

Motor Cut Outs—In case of damage to a traction motor, switches are provided to disconnect this motor from the circuit. The motor cut-out panel, as shown in Fig. 11, consists of four 400 ampere knife switches, which are connected in the ground side of the motor fields.

Each of these knife blades is covered by an interlock barrier which must be opened before the knife blades may be opened. This interlock barrier opens the control circuit to a 3000 volt electropneumatic switch, connected in the motor circuit just ahead of the armature of the motor to be cut out. By this means, both sides of the motor to be cut out are disconnected from the circuit. The opening of a remote controlled switch ahead of the motor armature, by the barrier interlock, eliminates the possibility of opening the 3000 volt circuit on the knife blades.

Inductive Field Shunts—Two additional running speeds are obtained in each of the three motor combinations by the use of two inductive field shunts. These shunts, Fig. 12, are similar to a transformer in construction, consisting of copper coils with a laminated iron circuit. They are assembled in sheet steel cases and are provided with forced ventilation by individual blowers, which run only when the shunts are in use.

Each shunt takes 15 percent of the current from the motor fields making a total shunting of 30 percent. The use of a divided shunt not only gives an additional running speed, but has proven a decided advantage in service, in permitting the use of the shunt on heavy grades where the armature current peak, which would be caused by the use of a single 30 percent shunt, would prohibit its use.

The field shunts are connected across the motor fields by two four-switch, electropneumatically operated cam switch groups. These groups are similar in construction and operation to the motor combination groups, and the switches are provided with magnetic blowouts and arc shields.

Main Motor Field Reverser—The reverser consists of a sixteen switch cam switch group with an interlock drum mounted on the cam shaft. The use of cam-operated switches for a reverser permits of increased insulation between contacts, and requires less attention for inspection and maintenance than the drum type.

Regeneration Change-Over—An eight switch group of cam switches is provided to insert the axle-generator armature in the field circuit for excitation of the fields during regeneration.

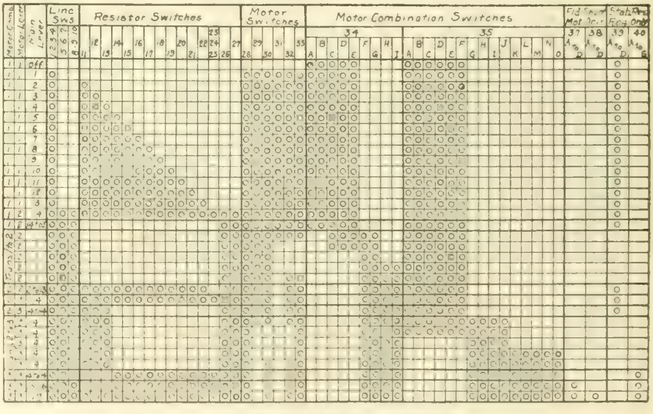
Motor Comb
Line Sws
Resistor Switches
Motor Switches
Motor Combination Switches
34
35
Fld Sh. Mot Gr.
Stab Res. Grd
37
38
39
40
Off

FIG. 9—SEQUENCE OF SWITCHES IN MAIN MOTOR CIRCUITS

[illegible]

Stabilizing Resistance Cam Switches—One group of four cam switches is used to connect the stabilizing resistors from the motor armatures to ground, in the No. 1 and No. 2 combinations regenerating. In the No. 3 combination, six switches of a seven switch group are used to connect the three banks of stabilizing resistance from the three sets of motor armatures to ground, the remaining switch being used to parallel the

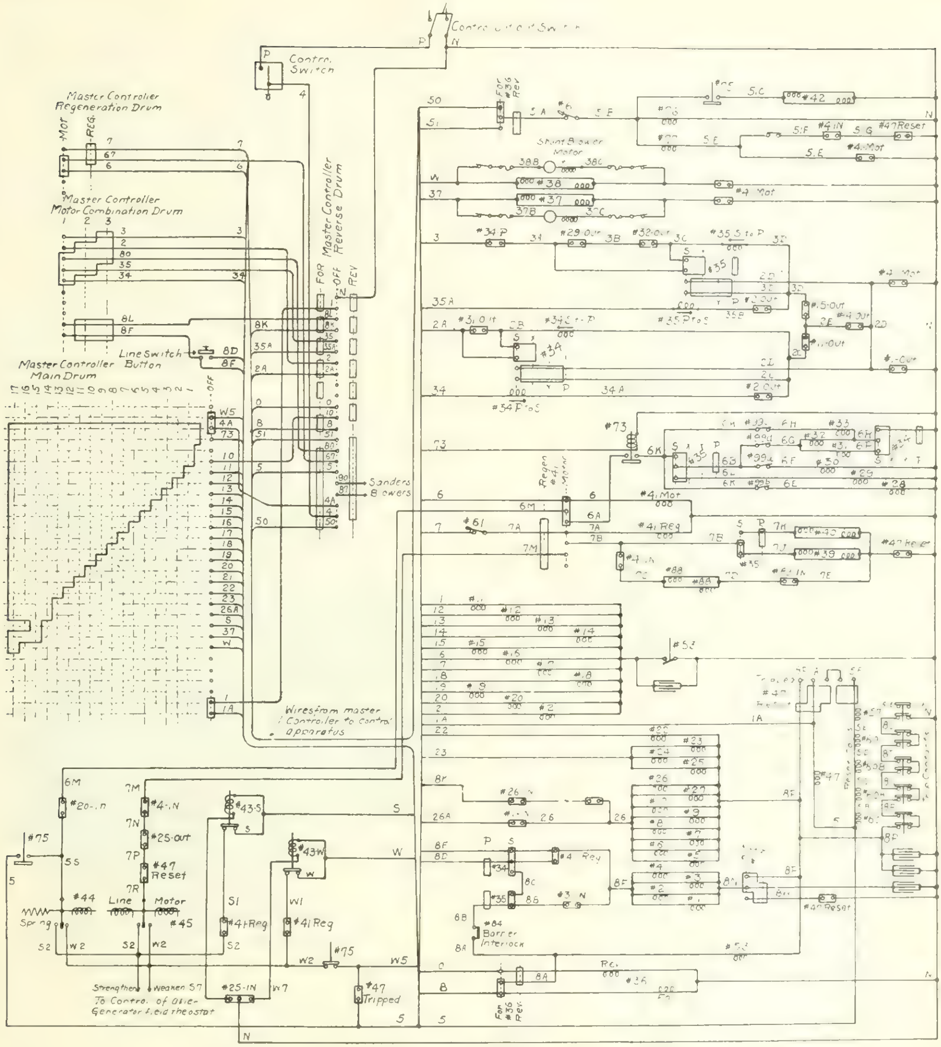

FIG. 10—SCHEMATIC DIAGRAM OF MAIN CONTROL CIRCUITS

APPARATUS NUMBERS

1 to 10—Line Switches.
11 to 27—Resistor Switches.
28 to 33—Motor Switches.
34 A to I—Motor Combination Cam Switch Group No. 1 to No. 3.
35 A to O—Motor Combination Cam Switch Group No. 2 to No. 3.
36 A to P—Reverser Cam Switch Group.
37 A to D—Field Shunt Cam Switch Group No. 1.
38 A to D—Field Shunt Cam Switch Group No. 2.
39 A to D—Stabilizing Resistance Cam Switch Group No. 1 and No. 2.
40 A to G—Stabilizing Resistance Cam Switch Group No. 3.
41 A to H—Regenerating Change-over Cam Switch Group.
42 A to I—Auxiliary Change-over Cam Switch Group.
43 S and 43W—Notching Relays.
44—Axle Generator Voltage Regulating Relay.
45—Balancing Relay.
47—Tripping Drum.
51—Motor Generator Starting Resistance Switch.
53—Resistor Switch Tripping Relay.
57—Over-Voltage Trip Relay.
60—Trolley Overload Trip Relay.
60A—No. 2 and No. 3 Motor Overload Trip Relay.
60B—No. 4 and No. 5 Motor Overload Trip Relay.
60C—No. 1 and No. 6 Motor Overload Trip Relay.
61—Axle Generator and Regenerating Cutout Switch.
73—Motor Switch Interlocking Relay.
75—Auxiliary Transfer Relay.
76—Axle Generator Field Switch.
77—Axle Generator Over-voltage Field Switch.
81—Main 3000 Volt Knife Cutout Switch.
87—Main Motor Blower Switch.
88—No. 1 Blower Regenerating Interlock Valve.
88A—No. 2 Blower Regenerating Interlock Valve.
89—Air Brake Emergency Cutout Switch.
91—Sander Switch.
99—Main Motor Cutouts.
99A—No. 1 Motor Cutout Switch.
99B—No. 2 and No. 3 Motor Cutout Switch.
99C—No. 4 and No. 5 Motor Cutout Switch.
99D—No. 6 Motor Cutout Switch.

two axle-generator armatures for supplying field excitation to the three sets of motor fields.

Installation of Main Wiring—To provide proper protection, all the cable runs between compartments are installed in iron pipe conduit. In the low-voltage and main resistor compartments, bare copper strap is used for interconnections between the various pieces of apparatus. This form of connection occupies much less space than cable and is fireproof.

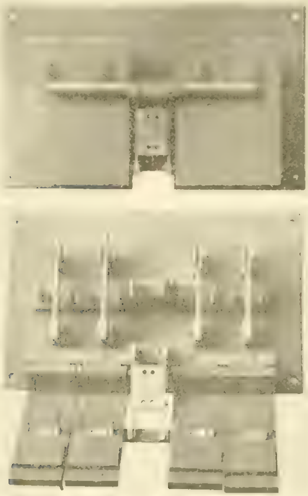

FIG. 11—MOTOR CUT-OUT BOARD

With switches closed in upper view and barriers open in lower view

FIG. [illegible]

CONTROL SCHEMATIC.

Having determined the proper number and type of switches and contacts to establish the various motor groupings and the order in which these switches are to be closed and opened, the next step in the general design was the development of the control schematic.

The sequence diagram, Fig. 9, naturally forms the basis for the control schematic. The simplest possible schematic was first laid out from the sequence diagram, showing the master controller contacts required to close the various switches, and the circuits from the controller to the coils of the switches. This simple schematic was then analyzed and interlocks provided to protect the equipment against injury, due to improper manipulation of the controller or failure of any contact or coil in the circuit.

Fig. 10 shows, in schematic form, the control circuits on the locomotive concerned with the operation of the main control. Current for operation of the control apparatus is taken from an 85 volt generator, or from an 80 volt battery when the generator is not running.

When the control circuits, as shown in Fig. 10, are examined in the various groups into which they naturally fall, they will be found to be comparatively simple.

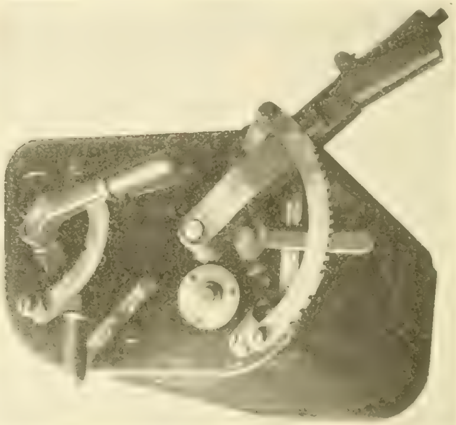

FIG. 13—TOP VIEW OF MASTER CONTROLLER

Upper right—main handle, 17 positions. Center right—reversing lever. Upper left—motor combination lever. Lower left—regeneration lever. Just below the pivot of the main operating handle is a line switch button which permits the motorman to come in on any motor combination, after a period of coasting or regenerating.

The control of the reverser and line switches forms one group, the line switches being so interlocked that they cannot be closed until the master controller main drum has been moved to the first position, and the reverser to the position indicated by the master controller reverser handle.

The control of the regeneration change-over and the motor switches forms another distinct group. These switches are interlocked in a manner similar to the line switches, so that they cannot be closed until the master controller main drum has been moved to the first position and the regeneration change-over has thrown fully to the position indicated by the master controller regeneration handle.

To complete the power circuit to the main motors, it is necessary to have both the line and the motor switches closed. As these switches are in two separate control circuits, it is necessary to energize two separate wires from the main drum of the master controller to complete the main circuits to the motors.

The control circuit of the resistance switches forms a group which is associated with the line switch group by reason of the special arrangement for opening the circuit by the over-load and over-voltage trip relays. An operation of any one of the over-load trips or the over-voltage trip will, through a system of progressive interlocking, gradually insert the main resistance before finally opening the circuit. This arrangement not only reduces the arcing duty on the individual switches, but prevents the objectionable voltage surges in the motors and line which would be caused by the sudden rupture of a heavy over-load or short-circuit.

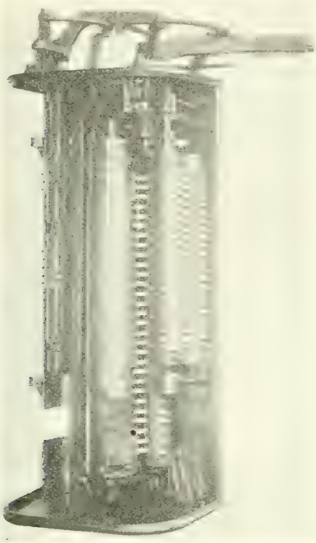

FIG. 14—MASTER CONTROLLER WITH COVERS OFF

The motor combination or transition groups, used to set up the different combinations of the main motors, are controlled directly from the motor combination drum in the master controller, and the "set up" for any combination may be made with the main handle in the *Off* position. In making the shunting transitions from one combination to another, during acceleration, the operating circuits to these groups are so interlocked that the switches will not close until the proper resistance for the transition has been inserted by first moving the main handle back to open a certain number of resistance switches.

The field shunt switches and the small blowers for the shunts are controlled directly from the main drum of the master controller, and are so interlocked that they will operate only during motoring.

The operating coils of the axle-generator field switches *76* and *77* are so connected that the field circuit is completed only when the master controller reverse handle is thrown to one of the operating positions.

FIG. 15—OVERLOAD TRIPS

The contacts of the *77* field switch are connected in the circuit of the arm of the axle-generator field rheostat, and an interlock on the over-voltage trip is connected in the circuit of coil of *77*. An operation of the over-voltage trip will open *77*, thereby inserting all field resistance that may have been cut out by the movement of the rheostat arm. This action quickly reduces the axle-generator voltage responsible for the over-voltage on the main motors.

The control of the axle-generator voltage forms another group of circuits which is largely independent of the other circuits. During motoring and coasting, the voltage is held constant by a voltage regulating relay, for operation of the compressor and blowers, as outlined in the description of the auxiliary circuits.*

FIG. 16—OVER-VOLTAGE TRIPS

When starting regeneration and while on resistance notches in the regenerating connections, the axle-generator voltage is controlled by a balancing relay, which tends to balance locomotive voltage with line voltage. When all main grid resistance is cut out in regeneration, the axle-generator voltage is controlled manually from the master controller main handle on the 15, 16, and 17 notches. Notching relays are used to limit the movement of the axle-generator rheostat arm to one notch for each movement of the main handle from *16* to *17* or *16* to *15*. The main motor field strength is regulated manually, by this means, to adjust the value of the regenerated current.

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*See article on "Auxiliary and Lighting Control Equipment" by Mr. J. A. Clarke, Jr., in this issue of the JOURNAL, p. 244.

CONTROL APPARATUS

The control schematic forms the basis for the selection and electrical design of the control equipment. A portion of the equipment may be classified as purely control equipment, such as the master controller and certain of the relays. The greater portion of the control circuits, however, is made up of the operating coils and interlock contacts of the line switches, resistance switches and cam switch groups. The control current required to operate one of the magnet-valves on any of the switches or cam groups is less than a quarter of an ampere. The low currents handled on the control circuits tend toward great reliability and low maintenance, as there is practically no burning or arcing on the master controller or other contacts.

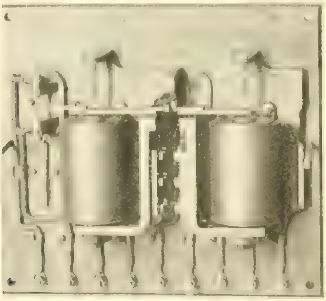
FIG. 17 BALANCING RELAY

The Master Controller—An unusually large number of accelerating resistance steps was provided on this locomotive to insure smooth acceleration and to permit a high rate of acceleration with less tendency to slip the drivers due to current peaks. In addition to the three running speeds provided by the three motor combinations, there are, as previously noted, two shunt field running notches available in each of the three motor combinations. This makes a total of 45 accelerating and running positions for the main handle. This number of notches on one drum would have required an inconveniently large angular movement of the main handle, and a large and heavy main drum.

In order to reduce the angular movement of the main handle, to simplify the mechanical interlocking in the controller and to provide for starting regeneration in any motor combination, a novel and convenient arrangement of controller levers is employed. A motor combination drum is used to set up the different motor combinations, the main drum carrying only 14 resistance steps and two field shunt steps. A reverse drum is used to control the direction of movement, and a regeneration drum is provided to set up the proper connections for either motoring or regenerating.

The construction of the controller is exceedingly simple notwithstanding the fact that motoring or regenerative braking is provided in three different combinations of the main motors. Fig. 13 shows the arrangement of the operating handles and Fig. 14 shows the drums controlled by these handles.

Overload Trip Relays—The construction of these relays is shown in Fig. 15. The setting of the relay is adjusted by varying the air-gap between the swinging armature and the magnet core. As no springs are used in the adjustment of the setting of the relay, no periodic testing or checking of the setting is required. An excess current in the main coil of the relay *60* lifts the armature to the magnet core thereby striking and raising the rod carrying the contact discs. A collar on the rod engages a latch in the raised position, which is released to reset the relay by a small magnet coil actuated by a reset contact on the main drum, which turns a drum *47*, closing several contacts.

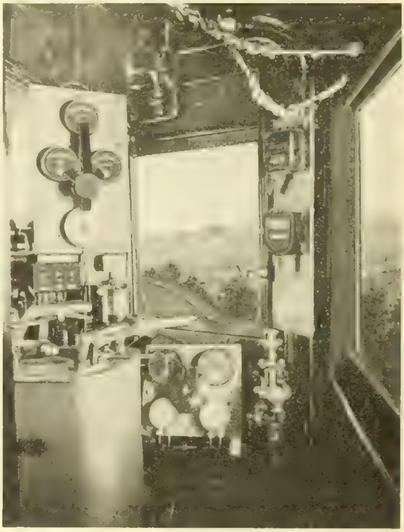
FIG. 18 VIEW OF OPERATING CAB

Over-Voltage Trip Relay—This relay is similar in construction to the over-load relays, a wire wound coil being substituted for the strap copper coil.

Balancing Relay—This relay, Fig. 17, is used to balance the locomotive voltage automatically with line voltage when starting regeneration. It consists of two coils connected, through a high resistance, one to the line and one to the motors. These coils act on a common armature pivoted at a point between the two coils. When the locomotive voltage equals line voltage, the armature is held midway or balanced between two contacts. If the line voltage is higher than the locomotive voltage, as is the case when starting regeneration, the armature is pulled down against the strengthening contact. Energizing this contact causes the axle-generator rheostat to cut out field resistance, thereby raising the axle-generator voltage, the main field strength and finally the main motor voltage until a balance is obtained.

Installation of Control Wiring—Six control junction panels are located at convenient places in the locomotive. All of the wires from the controllers and the various pieces of apparatus are brought to these junction panels, where all interconnections are made. This method of installing the control wiring eliminates all cross pulls in conduits and simplifies the wiring layout. Each conduit run is a straight pull of wires from a piece of apparatus to a junction panel or between two junction panels.

OPERATION OF CONTROL IN MOTORING

In starting an acceleration from standstill, the motor combination lever must be in the No. 1 position, the regeneration lever at *motoring* and the reverse lever in *forward* or *reverse* as required. The main handle is then notched out to the 14th notch, where all resistance is cut out of circuit in the No. 1 combination. At this point, the motor combination handle is thrown to No. 2. The "shunting" transition to the second combination is not made, however, until the main handle is moved back to the first notch to insert the proper value of resistance for the two sets of three motors. The accelerating resistance is then cut out in the second combination by notching the main handle out to the 14th notch, as in the No. 1 combination.

The motor combination lever is now thrown to No. 3 and the main handle backed off to the 4th notch. The opening of the No. 14 resistance switch on the fourth notch, completes the control circuit to make the transition from the second to the third motor combination. The main resistance is now cut out in the third combination by notching the main handle out to the 14th position, which is the full field running position. Two higher speeds are obtained by shunting the fields on the 15th and 17th positions of the main handle. The shunt field notches may be used in any of the three combinations by moving the main handle up to the 15th or 17th notches. The interlocking is so arranged that it is impossible to close the line switches in the No. 2 or No. 3 motor combinations out of order, without first pressing the "line switch button" on the master controller. This arrangement prevents the engine man from unknowingly closing the line switches in an attempt to start from rest in the No. 2 or No. 3 combination. When coasting, however, it is possible and proper to close the line switches in either the No. 2 or No. 3 combination according to the coasting, by pulling the speed lever up to the No. 1 position and pushing the "line switch button".

The ease and rapidity with which the enginemen have become familiar with this method of manipulation is a tribute, not only to the simplicity of the control, but to the enthusiasm and co-operation of the men themselves.

OPERATION OF THE CONTROL REGENERATING

In the design of a system of control for direct-current regenerative braking, there are two distinct considerations involved. The first is the method of paralleling the motors, as generators, with the substation generators, without causing a surge in the train. The second is the control of the locomotive generated voltage to obtain and adjust the required braking effort. An automatic method of balancing the locomotive voltage with the line voltage was selected as being the most reliable, and requiring the least effort in manipulation.

To start regeneration, at any speed, the main handle, if notched up in motoring, must first be thrown to the off position. The motor combination handle is then moved to set up the motor combination approximately corresponding to the speed at which the locomotive is moving. The regeneration lever is next thrown to the regeneration position. This connects the axle-generator exciters and the stabilizing resistance in the motor field circuits. As soon as the axle-generator field rheostat arm has returned to the weak field position, as indicated by a pilot lamp, the main controller handle is notched out to the first position. This connects the locomotive motors, as separately excited generators, to the line through the total main grid resistance.

Under normal conditions, the voltage generated by the locomotive is always lower than line voltage when first closing the line switches. The higher line voltage will then force a small motoring current through the locomotive motors, with all resistance in circuit. This current is not sufficient to pull out the train slack and is quickly reduced by the action of the balancing relay in raising the locomotive voltage to equal line voltage.

With the locomotive voltage balanced to line voltage, there is no current flowing through the main grid resistance, which may now be cut out of circuit by moving the main handle out to the 16th notch. The closing of the last resistance switch, disconnects the contacts of the balancing relay from circuit, the control of the axle-generator field rheostat being transferred for manual control to the *15*, *16* and *17* notches on the main drum of the master controller.

The *16* notch is a neutral or holding position and a movement of the main handle from this position to *15* and back, or to *17* and back will establish circuits to move the arm of the axle-generator field rheostat one point in the strong field or the weak field direction respectively. The same wire which causes a movement of the rheostat arm also energizes the coil of a time-element notching relay. This relay is so connected and adjusted that its contacts will open the operating circuit to the rheostat, as soon as sufficient time has elapsed for the rheostat arm to move one point. No further movement of the rheostat arm can be obtained, until the controller handle has been moved back to the *16* position to release the notching relay. This arrangemen provides a positive notching of the axle-generator field rheostat through 57 points by the use of only three positions on the master controller main drum. Having established the regeneration connections and automatically balanced the locomotive voltage with the line, the operator now has, in effect, a controller with 57 notches with which to adjust the value of the regenerated current.

The absolute smoothness and ease with which a heavy passenger train may be handled down the long mountain grades is even yet a source of unfailing comment. Regeneration is started at the top of the grade and the train slack bunched so gradually that it is impossible for a person riding in the train to tell when the regenerative braking is applied to the train.

In regular operation the value of the regenerated current is set at the top of the grade at a known value, to hold the train at certain speed. If so desired, the train may be taken down the 20 miles of two percent grade on the east slope of the Rockies, at a speed not varying over one mile per hour above or below a set value, without the necessity of any manipulation of the control.

The Auxiliary and Lighting Control Equipment

Of the Chicago, Milwaukee & St. Paul Locomotives

JOHN A. CLARKE, JR.

WHILE the traction motors and their control constitute the most important part of the equipment of an electric locomotive, it is essential that they be backed up with sufficient auxiliary apparatus to insure the complete and proper operation of the locomotive and make possible such convenient manipulation as is necessary in a machine involving such a variety of functions. The locomotive is the power plant of the train; not only does it furnish the motive power for pulling the train over the road, but it also supplies the means by which its speed is regulated and it is brought to a stop, when necessary. It supplies the heat for the train and, in this case, lights the train as well. All this must be done in such a way as to provide the greatest convenience and comfort to passengers, and the minimum amount of labor on the part of the train crew. With these facts in mind and a wealth of engineering specialists to handle each separate problem, results have been secured on the Chicago, Milwaukee & St. Paul locomotives which justify the effort and are a distinct advance in the art.

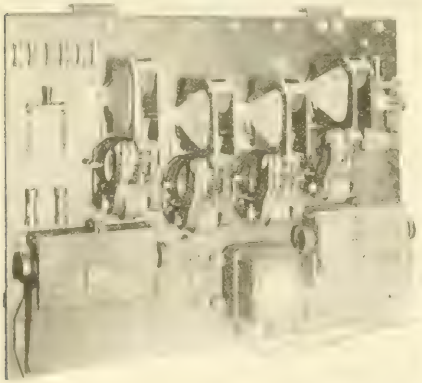

FIG. 1—AUXILIARY LIGHTING CONTROL PANEL

The high voltage of the line current precluded its use on the control and auxiliary circuits, and made necessary a secondary or auxiliary source of power. For this purpose a 35 kilowatt motor-generator set was chosen, together with a 378 ampere-hour storage battery. The battery floats across the terminals of the generator, assisting it on the peak loads and receiving charge when the load is light. In addition, there are two 40 kilowatt axle-driven generators mounted on the bogie trucks. These are used to supply current for the traction motor fields during regeneration, but when pulling or coasting above ten miles an hour, supply current for the air compressor motor, and for the traction motor blowers, whenever the load and grade conditions require them.

The auxiliary control apparatus includes, besides the compressor motor and the traction motor blowers, the complete system for lighting the train and charging the train batteries, the locomotive cab lights and headlights, the boiler blower motor, the electric footwarmers, the control for the pantagraphs, and the main switches and fuses for the control and protection of these various auxiliaries. The auxiliary circuit voltage chosen was 85 volts, which is satisfactory for control circuits and auxiliary motors. It provides a margin for charging locomotive and train batteries and will maintain the train lighting voltage over a wide range of load and line voltage variation.

The motor-generator set consists of a 3000 volt compound-wound, double-commutator motor direct connected to a shunt-wound generator. The shunt field of the motor is connected directly to the battery through the main control cutout switch as shown in Fig. 2, and is not fused. This arrangement insures a safe speed at zero load. The high-voltage motor is protected from overload by three bomb-type expulsion fuses of graded capacity, Fig. 3, connected to a resistor, and so arranged that the fuses blow successively in the reverse order of their capacity, adding resistance to the circuit each time, so that the current is greatly reduced when the final fuse blows.

The motor-generator is started by running the generator as a motor from the storage battery, is brought up to about two-thirds speed, and then connected to the 3000 volt line. A three-step drum type starting switch is used, Fig. 4, which is mounted close to the motor-generator. The first step inserts a small starting resistance, which is short-circuited on the second step, while the third step closes the high voltage contactor, Fig. 5, which connects the motor to the line. An interlock on this contactor closes a holding circuit for its magnet coil, as well as for the coil of the switch which connects the generator to the storage battery.

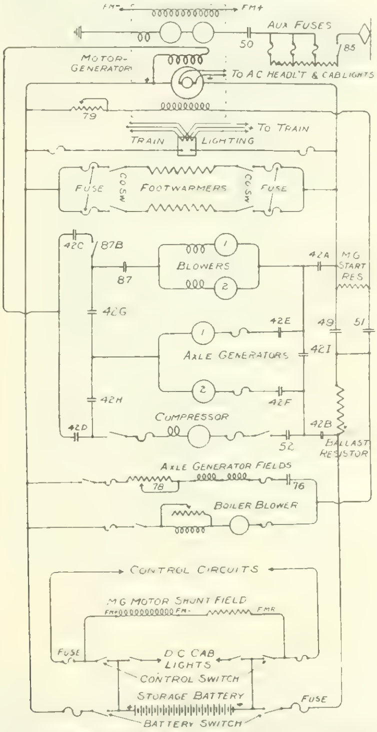

FIG. 2—SCHEMATIC DIAGRAM OF AUXILIARY CIRCUIT

The handle of the starting switch works against a spring which returns it to its *Off* position when it is released. The motor-generator is shut down by any one of three push-button "stopping" switches which are normally held closed, but which open these holding circuits when they are operated. One of these stopping switches is located in each operating cab, adjacent to the pantagraph control switch, so that the set can be shut down conveniently and quickly before dropping the pantagraphs, thereby eliminating any danger of an arc at the trolley wire. The third switch is mounted close to the starting switch where it is convenient for the fireman, or for the inspector at the roundhouse.

The control for the two air-operated pantagraphs is arranged to provide complete protection for a man entering a high-voltage compartment. The air supply to each pantagraph is controlled by a large magnet valve and these are operated from two small drum-type control switches, each provided with a specially designed handle which is removable only in the *Both down* position of the switch. The switch has three other positions which provide for raising either the forward or rear pantagraphs alone, or the two together. The control circuits are so interlocked that with one switch in the *Both up* position, the other switch can be placed to raise the pantagraphs as desired. Any other combination will immediately lower both pantagraphs, so that the removal of the control handle from either of these switches absolutely cuts the locomotive away from the high voltage trolley line.

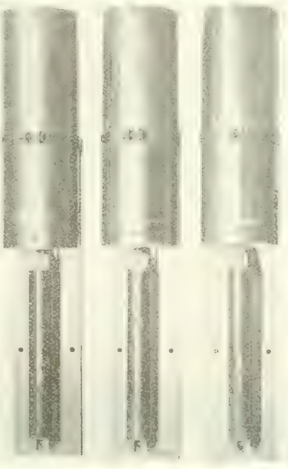

FIG. 3—3000 VOLT AUXILIARY CIRCUIT FUSES

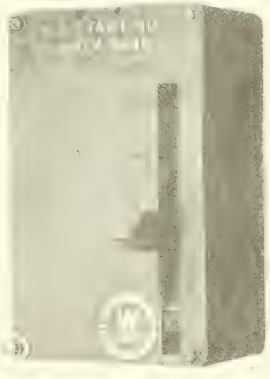

FIG. 4—THREE STEP DRUM TYPE STARTING SWITCH FOR MOTOR-GENERATOR

The voltage of the generator is automatically maintained constant by means of a motor-driven rheostat, Fig. 6, in its shunt field, which is controlled by a voltage regulating relay, Fig. 7, through a set of reversing relays or switches. The coil of this voltage regulating relay is connected across the terminals of the generator and works against a spring to control a three-way contact attached to its armature. This armature is electrically connected to one side of the control circuit and "floats" in a center or open-circuit position when the voltage is normal. Any change in voltage immediately causes the relay armature to close a pair of reversing switches which, in turn, close the armature circuit of the rheostat pilot motor in the proper direction to adjust the generator shunt field and correct the voltage. The rheostat pilot motor field coil is continuously in circuit whenever the generator is running. A dynamic braking resistance is permanently connected across the armature of this motor to secure an absolute stop the instant its armature is de-energized, and a damping coil, wound on the same spool as the main coil of the voltage regulating relay, is connected across this braking resistance to prevent hunting of the generator voltage. The shunt field resistor has a sufficient number of steps to provide proper voltage regulation at all loads and for a speed variation corresponding to changes of the line voltage between the setting of the over-voltage relay and half the normal line voltage. This wide range of operation is required on account of the power limiting device on the trolley and feeder system, which automatically reduces the voltage whenever the total load in a given section of railroad exceeds the maximum allowable peak load.

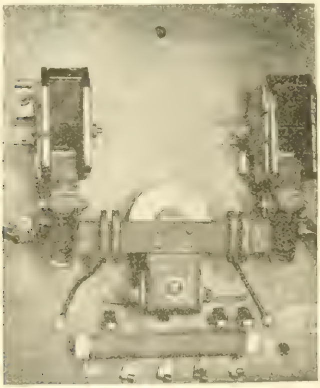

FIG. 5—AUXILIARY CIRCUIT HIGH VOLTAGE CONTACTOR

The storage battery consists of 38 cells mounted in two compartments just below the floor of the cab at its center. These compartments are lined to protect the battery from low temperatures and have convenient outside doors to provide access for inspection at the roundhouse. An ampere-hour meter, set to run slow on charge, indicates the amount of charge out of the battery at any time. A small rheostat in series with the coil of the generator voltage-regulating relay permits small variations in the charging voltage, in order to take care of abnormal discharges. The battery is kept fully charged in regular service on the road, and the equalizing charges are made at the roundhouse during the periodic inspections.

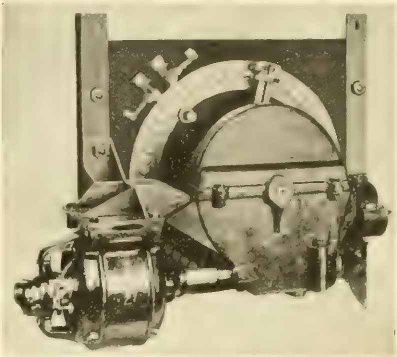

FIG. 6—MOTOR-DRIVEN SHUNT FIELD RHEOSTAT

The fields of the two axle-generators are connected in series across the 85 volt circuit of the motor-generator, and the voltage of these axle-generators is maintained constant, except when the main motors are regenerating, by means of a voltage regulating system similar to that described for the motor-generator. During regeneration they are controlled by a balancing relay and manually through the master controller.*

The compressor motor for the airbrake system, which is the largest single part of the auxiliary load, is transferred automatically from the motor-generator and battery to the axle generators, whenever the locomotive exceeds a speed of approximately ten miles an hour while pulling, coasting or using the air brakes. This is accomplished by means of a transfer relay, Fig. 8, connected across the terminals of one axle generator. When this relay picks up, it closes the control circuit to the magnet valves of a group of cam switches, Fig. 9, which operate so as to set up the desired circuits.

FIG. 7—VOLTAGE REGULATING RELAY AND REVERSING RELAYS
Controlling the motor-driven shunt field rheostat.

The air compressor furnishes air for the train brake system, the electropneumatic control system, signals, locomotive whistle and the atomizer for the heating boiler burners when starting the boiler. It is a 150 foot compound type, driven by a series motor. It is automatically started and stopped by an air-operated governor which controls a magnetically-operated contactor in its motor circuit. This contactor is also controlled by two snap switches. One is mounted over the governor for cutting it off electrically for inspection or adjustment, and the other is located beside the motor-generator switch, so that the compressor may be cut off when starting the motor-generator from the storage battery. In order to compensate for the heavy starting load of the compressor motor, there is a series field on the generator which is only energized when the compressor or blowers are running.

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*See article by P. L. Mardis in this issue, p. 235.

The train lighting circuits are connected directly across the motor-generator and controlled from a train lighting panel on the locomotive. Three train line wires run through the train from three knife switches on the train lighting panel, as shown in Fig. 10. One of these wires is the positive generator lead. The negative lead from the generator is carried through a circuit-breaker and the train battery charging rheostat. Then it is divided, one branch leading through the battery knife switch directly to the negative side of the train batteries. The other branch passes through the train lamp rheostat and the lamp knife switch to the negative side of the train lamps. With either the circuit-breaker or the generator knife switch open and the lamp rheostat all cut out, the train lamps are lighted from the train batteries. This "loop" in the locomotive is in parallel with loop switches in the train, although the latter are used only when the train is disconnected from the locomotive. By closing both the circuit-breaker and the generator knife switch on the train lighting panel, and adjusting the lamp and battery rheostats for the particular load, the train batteries are charged and the train lamps are lighted from the locomotive generator.

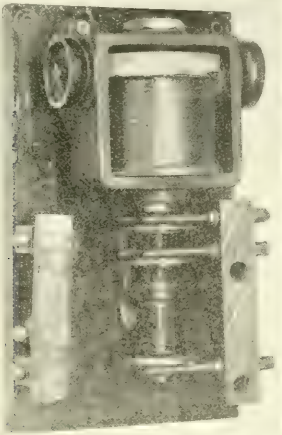

FIG. 8—AUXILIARY CIRCUIT TRANSFER RELAY

In order to eliminate any momentary flicker in the train lights at the instant the compressor starts or stops, a permanent "ballast" resistor of small ohmic value is connected in the negative lead between the generator and the storage battery, and the compressor motor is connected on the battery side of this resistor. The larger part of the compressor starting current is thereby drawn from the battery and a definite means of dividing the load between the generator and the battery is provided.

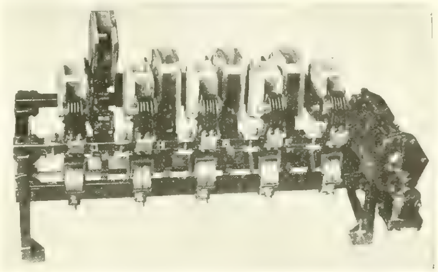

FIG. 9—AUXILIARY CIRCUIT CHANGE-OVER CAM SWITCHES

The two traction motor blowers, each driven by an 85 volt series motor, take their power from the axle-generators. In an emergency they can be operated from the motor-generator and the storage battery by closing an emergency knife switch installed for this purpose. They are connected in circuit by a single magnetically-operated contactor, a duplicate of those used for the compressor motor and for connecting the motor-generator to the battery. This contactor is controlled by a snap switch in each operating cab, and the circuit interlocked through the master controller reverse drum, so that it can be controlled only from the actual operating end.

The current for the various control circuits is taken from the storage battery inside of the main battery fuses. Thus the blowing of a main battery fuse, or the stopping of the motor-generator, does not affect the control of the main motor circuits. This arrangement is also convenient for inspection and testing the sequence of operation when the pantagraph is down and the motor-generator is not running. The control circuits are protected by their own fuses and a separate cutout switch is used to disconnect them from the storage battery.

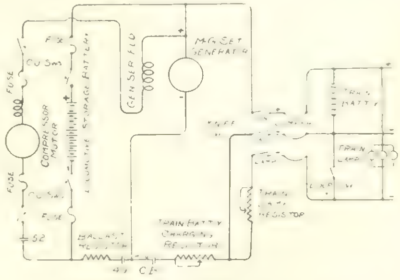

FIG. 10—DIAGRAM OF THE TRAIN LIGHTING CIRCUITS

The locomotive direct-current cab lights are also connected directly to the battery with separate fuses and cutout switches. The several groups of lamps are individually controlled by push-button switches conveniently located. A small resistor is connected in series with each direct-current locomotive cab light in order to adapt the 85 volt line for the railway company's standard 64 volt lamps used in the train. Current for the railway company's standard alternating-current headlight is secured from slip rings on the low potential windings of the motor-generator through a small transformer, and a three-position canopy control switch is used for dimming the headlight when passing another train. Alternate lamps in the locomotive side aisles are also lighted by alternating-current from the same slip rings that furnish current for the headlight and they are controlled by a push button switch and fused.

A small, variable speed motor, driving a blower for the steam-heating boiler, is connected on the battery side of the switches between the motor-generator and the battery, and is separately controlled and provided with its own fuses and cutout switch. A one kilowatt electric heater is located on the floor of each operating cab as a foot-warmer. It is connected to the motor-generator only, so that it will not discharge the storage battery if accidently left on when the locomotive is standing idle.

In determining the arrangement of the various pieces of apparatus on the locomotive, consideration was given to the location of the control switches and fuses for the auxiliaries so that they would be convenient for the fireman on the road. All of these switches which are not mounted elsewhere for some particular purpose, are assembled on the "Auxiliary Panel Board", Fig. 1, which is mounted beside the low-voltage end of the motor-generator set and facing the aisle. Here are located the main battery and main control cutout switches and fuses, the motor-generator starting and stopping switches, the main cab lighting snap switches and a compressor control cutout switch. Also the four contactors for the compressor, the traction motor blowers, the motor-generator and the storage battery respectively, and the battery ampere-hour meter.

The auxiliary panel and the train lighting panel are located on either side of the boiler compartment and on the same aisle as the boiler burners and gauges. Several locomotive lamps are connected in the train lighting circuit and so placed that the fireman's attention is immediately called to any change in the train lamp voltage. A loud-ringing signal bell is mounted near the center of the locomotive, with a push-button in each cab, so that the engineer can signal to the fireman at any time.

It can be seen that all the control for the auxiliary apparatus is grouped within a short distance of the center of the locomotive, so that the fireman can readily look after it. This insures the maximum efficiency in the operation of the various auxiliaries and provides the main traction motors and control with that uniform and reliable support which makes these locomotives so successful in the heavy mountain service in which they are operating.

Current Limiting Reactors Commonly Protect Both Service and Equipment

K. C. RANDALL

In the growth of power stations, especially very large ones, the possible concentration of power involves mechanical and electrical problems which have been largely appreciated for some time. Rather recently the matter of thermal capacity of apparatus has been added, so that fairly definite knowledge of the maximum current concentrations to which the equipment may be exposed is necessary to a full decision. This applies particularly in the choice of bus-bar supports, disconnecting switches and circuit breakers. It is quite customary to limit the concentration of current by reactors, even though the strength of the bus-bar supports, disconnecting switches, or ability of the circuit breaker be adequate without these current limiting devices. Hence the question may arise—why introduce the material expense of the reactor.

In such large stations, and also on large systems, the possible unlimited current concentration might develop forces exceeding those which bus-bar supports, disconnecting switches, etc., would be able to withstand. In such instances, reactors may limit the otherwise excessive currents to values within the strength limitations of the current interrupting ability of the equipment. Still the primary object of the reactors may have been for an entirely different purpose.

Generating stations commonly carry loads of a largely synchronous nature and to keep such apparatus in operation, it is necessary that the bus voltage shall be pretty well maintained. A bus subject to relative low resistance short-circuits will not hold up under such conditions, but one protected by adequate reactors much better maintains its voltage. Hence it is common practice to find systems employing reactors so arranged that heavy short-circuits, or similar disturbances, will not drop the voltage of the whole system and, therefore, affect the total synchronous load, but on the other hand will isolate the trouble to the particular feeder or part of the system directly concerned. So it follows that reactors primarily necessary to the protection of service, are also effective in reducing the burden on switching equipments, although not directly intended for that purpose.

The size and capacity of reactors and their location in the circuits of large systems involve the characteristics of the generating, transforming and transmission equipment, and also the plan of operation, for many methods of reactor grouping have been employed or proposed. The inductance of apparatus in series with the reactors is equally effective in limiting the current. Therefore, definite knowledge of the inductance of the apparatus, and the maximum permissible current, is necessary to an economical choice of reactors, as well for the protection of the service or apparatus involved.

Layout of Apparatus in the Cab

Of the Chicago, Milwaukee & St. Paul Locomotives

C. C. Whittaker

THE ARRANGEMENT of the apparatus in the cab of an electric locomotive has much to do with its successful operation from various standpoints, such as ease of maintenance, life of apparatus, accessibility for adjustment in operation, etc. The arrangement of apparatus in the Chicago, Milwaukee & St. Paul locomotives was determined upon after a careful consideration of the theoretically ideal combination and of the experience which had been gained through the design and operation of various other types of electric locomotives of essentially similar operating characteristics. The principal characteristics of the arrangement adopted are as follows:—

1—The heaviest pieces of apparatus are mounted well within the truck center pin limits, and on the center line of the locomotive, in order to reduce both swinging and rolling "dumb-bell" effect.

2—The weight is distributed evenly about both longitudinal and transverse center lines.

3—The apparatus is mounted so that the parts are accessible for inspection and repairs, or can be removed with minimum disturbance or adjacent parts.

4—The pantagraphs are located over the truck center pins, to minimize the effect of side displacement on curves.

5—The apparatus is arranged so that a minimum length of cab and wiring results.

6—The apparatus is installed on a central deck, with an aisle on each side to facilitate inspection and to afford the greatest possible protection to the apparatus in case of a wreck.

7—All high tension apparatus is enclosed in a grounded compartment as a safety measure.

8—The minimum amount of inflammable material is employed and cable is protected by conduit to reduce fire hazard.

A longitudinal weight distribution diagram of the cab, including the principal pieces of apparatus, is given in Fig. 1. The full line shows the weight per foot length of cab for average running conditions; the dotted line shows the conditions when the locomotive has a full complement of sand, oil and water. This location in the center of the cab of a large proportion of the total mass supported by the trucks, indicates why these locomotives have shown no tendency to "nose" since entering service.

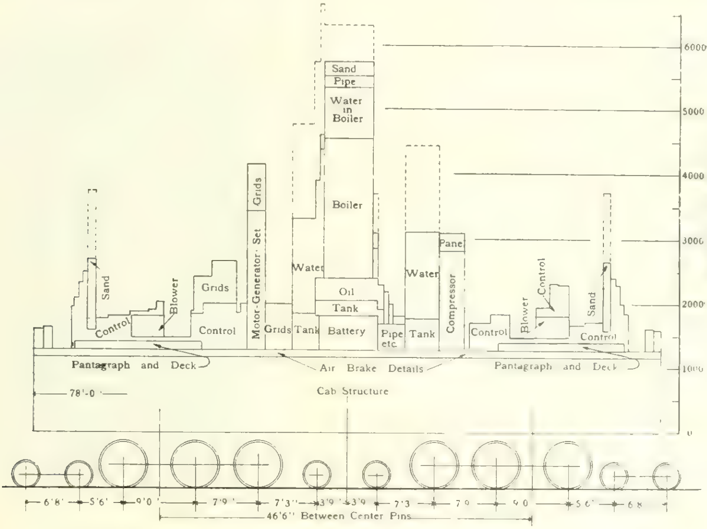

FIG. 1—DIAGRAM OF WEIGHT DISTRIBUTION ON THE LOCOMOTIVE CAB [illegible]

An engineer's compartment is located at each end of the cab, thus affording an unrestricted vision of the track to the engineer, even on curves. The engineer's compartment has all walls and ceiling lagged and is supplied with double glass windows, since temperatures as low as 50 degrees below zero are encountered. In this compartment, the parts of the air brake system most sensitive to freezing—the triple valve, transfer valve and reducing valves—are mounted directly over a steam radiator. An electric foot warmer is located under the engineer's foot rest.

The pantagraphs are located as nearly as possible over the truck center pins. Each pantagraph is mounted on and insulated from an iron deck which is, in turn, insulated from ground by porcelain insulators; the purpose being to prevent burning the roof if the pantagraph should be damaged. The insulators used for both pantagraph and deck are interchangable.

Each pantagraph circuit is provided with a disconnecting switch, Fig. 2, supplied with a sleet hood, and mounted on two insulators, similar to those used on the pantagraph. The pantagraph cable, before going to the main motor circuits, connects to another disconnecting switch inside of the cab, which is a duplicate of the two outside switches, except that the sleet hood is omitted.

There are two blower motors, each supplying forced ventilation for the motors of one truck. The intake to each blower motor is secured through four louvres located in the upper part of the cab side sheets. The outlet for the blower housing is approximately over the truck center pin. This outlet connects with the main air conduit by a flat sliding ring and sleeve construction which allows for relative motion, both vertical and horizontal, between the cab and the duct. The air duct is bolted rigidly to the main motor frames, one duct for each truck.

The cab structure is of usual Baldwin-Westinghouse design. A central equipment deck, raised with respect to the floor of the side aisles, affords ample space for the main motors. The roof is removable in five sections. There are also three removable side sheets, one for the motor-generator set and one for each of the blowers.

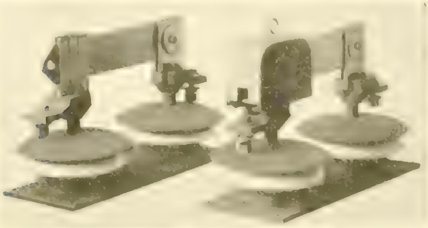
FIG. 2—PANTAGRAPH DISCONNECTING SWITCH

The equipment deck is divided into five spaces, four of which have sheet iron side walls forming compartments in which the electrical controlling apparatus is located. These side walls have inspection doors, conveniently located, by means of which a large part of the apparatus may be inspected from the side aisles.

The main line switches and resistor switches are mounted so that the arc blows toward the center of the locomotive. Asbestos barriers are located in front of the switches to confine the arc. This space is ventilated through the roof. Fig. 3 shows a rear view of a group of these switches. Each switch is a unit in itself and is designed so that most of its parts which require inspection can be reached from the rear.

The main accelerating grid resistors are mounted in cradles, which are assembled complete with grids, insulators and interconnections while on the floor; the whole assembly being then lifted into the cab. The resistors are provided with triple insulation. The insulation between individual grids and between grids and end frames is composed of mica washers. The frames are insulated from the supporting cradle by porcelain and bakelite duck insulating bolts. The cradles are, in turn, insulated from the cab supports by similar bolts.

Ventilation is obtained by having expanded metal in the lower half of the grid compartment walls and by providing ventilators in the roof. These ventilators may be controlled individually from the side aisles and may be completely closed, half opened, or fully opened; the position depending on operating conditions relative to snow. The stabilizing resistors differ from the accelerating resistors in that they are of low ohmic resistance and are subjected to larger currents. Where several grids are paralleled, the paralleled ends are welded together after being assembled in the frames. These grids have the same means of ventilation as the accelerating grids.

The train-heating equipment, consisting of a steam boiler, water tanks, oil tank, forced draught blower, oil and water feed pumps and other accessories, requires 30 percent of the total length of the equipment deck and the weight of this equipment is approximately eight percent of the total locomotive weight. The oil tank is mounted under the boiler and below the cab floor in order to minimize the fire risk.

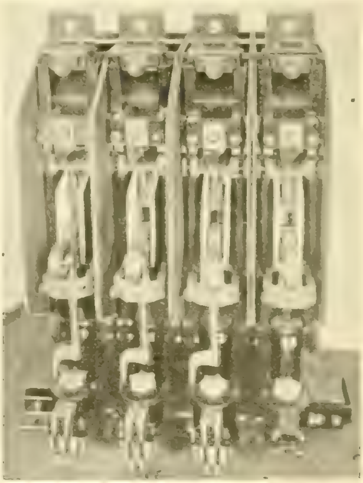
FIG. 3—REAR VIEW OF SWITCHES

The battery boxes are located just outside of the oil tank and are lagged on the inside with maple. The battery trays are arranged with flexible leads so that individual trays may be taken out for inspection.

The motor-generator set is mounted cross-wise of the deck to facilitate the removal of end housings and to avoid end thrust of the rotor.

The height from the rail to the center of gravity of the complete locomotive is 68 inches and that of the running gear complete with main motors is 43.75 inches. The relatively high center of gravity obtained with motors mounted in this way is of special importance from the standpoint of road characteristics of locomotive operations.

Switchboard Meter Connections for Alternating Current Circuits—VI

J. C. Group

SIX-PHASE CIRCUITS

SIX-PHASE circuits are used to supply power to the alternating-current side of rotary converters. The six-phase circuit is usually obtained from a transformer bank, the secondary of which is connected to the rotary converter by either a six-phase diametrical or a six-phase double-delta arrangement. A rotary converter operates with the minimum amount of heating when the power-factor in the six-phase supply circuit is 100 percent, for then the alternating-current is of the smallest value for a given direct-current load. It is therefore desirable to have a power-factor or reactive-factor meter connected to the six-phase circuit between the transformer bank and the rotary converter. In ordinary switchboard practice, a power-factor or reactive-factor meter is the only instrument that is connected to the low-tension side of the transformer bank, all other measurements being made on the high-tension or line side.

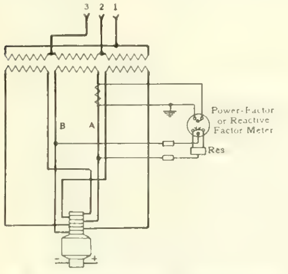

FIG. 70—SINGLE-PHASE POWER-FACTOR METER ON A SIX-PHASE CIRCUIT

With diametrical connection to rotary converter.

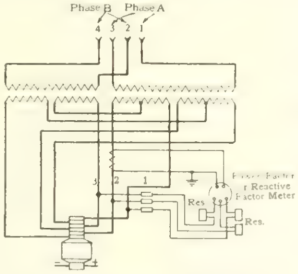

FIG. 71—SINGLE-PHASE POWER-FACTOR METER ON A SIX-PHASE CIRCUIT

With double delta connection to rotary converter.

In Fig. 70 a single-phase power-factor or reactive-factor meter is shown on a six-phase circuit with diametrical connection to the rotary converter. The primary of the transformer bank is three-phase. For the average installation, the alternating-current load taken by a rotary converter is very nearly balanced, and for that reason one single-phase meter may be used to check the condition of power-factor. The meter is connected to one of the three phases on the low-tension side of the transformer bank, the same as for a single-phase two-wire circuit. The small arrows representing the direction of currents from one terminal to another in the meter are for the condition where the voltage in the phase is in the direction from line *A* to line *B*.

The double-delta connection to a six-phase rotary converter is necessary when the power transformation is from two to six-phase as shown in Fig. 71. The secondaries of both the main and the teaser transformers consist of two windings. Each winding of the main transformer is connected in tee to one of the teaser windings respectively to form a three-phase circuit, and these two three-phase circuits are connected to the slip rings of the rotary converter so that corresponding leads of the two circuits are displaced 180 degrees in the converter armature, thus producing the double-delta arrangement. The three lines comprising either one of the three-phase circuits connected to the three points of one of the deltas may be treated exactly as a three-phase three-wire circuit, and since the six-phase load taken by a rotary converter is very nearly balanced, a three-phase power-factor or reactive-factor meter connected to one of these three-phase circuits is sufficient for checking the power-factor of the machine. In Fig. 71 the meter is connected to the three-phase circuit represented by lines *1*, *2* and *3* the same as for a three-phase three-wire circuit.

MEASUREMENT OF REACTIVE VOLT-AMPERES IN TWO-PHASE CIRCUITS

When the current in an alternating-current circuit is not in phase with the voltage, it may be thought of as being composed of two components, one in phase with the voltage and the other 90 degrees out of phase with the voltage, and in a vector diagram such a current can be readily resolved into two components for analytical purposes. This must not be misconstrued to mean that two or more separate currents actually flow in any conductor for that is not the case. There can be only one current in a given conductor, although it may be produced by the combination of a number of currents or component parts. However, for the purpose of making certain calculations or measurements current is considered as resolved into components and these components analyzed separately. At unity power-factor (when the current is in phase with the voltage) the torque-producing reaction in a wattmeter is proportional to the product of the current and voltage, but when the current is out of phase with the voltage, it is proportional to the product of the voltage and the component of the current in phase with the voltage. This component is equal to the current multiplied by the cosine of the angle by which the current is out of phase with the voltage. The component of the current which is 90 degrees out of phase with the voltage is equal to the product of the current and the sine of the angle by which the current is out of phase with the voltage. The total volt-amperes (the product of volts and amperes) in a circuit, where the current is out of phase with the voltage, may also be thought of as consisting of two components, one equal to the product of the voltage and the component of the current in phase with the voltage and the other equal to the product of the voltage and the component of the current 90 degrees out of phase with the voltage. The first component represents the actual power delivered by the circuit, and the other represents a loss in the circuit and is termed the "reactive volt amperes". The power in a single-phase circuit is represented by the expression $EI \cos \phi$, in a two-phase circuit by $2\,EI \cos \phi$, and in a three-phase circuit by $\sqrt{3}\,EI \cos \phi$, where for each case E is the line voltage, I the line current and ϕ the angle of lag or lead. It follows then that the reactive volt-amperes are represented by $EI \sin \phi$, $2\,EI \sin \phi$, $\sqrt{3}\,EI \sin \phi$ respectively.

It is sometimes desirable to measure the reactive volt-amperes in a circuit and, in order to do this with a wattmeter element, it is necessary to secure a voltage which is displaced in phase 90 degrees from the normal position for measuring power, so that at unity power-factor the wattmeter element does not show any measurement and at the maximum theoretical angle of lag or lead of 90 degrees the wattmeter will show full scale deflection. The reactive volt-amperes in a single-phase circuit cannot be measured by a wattmeter, for it is not possible to displace the voltage 90 degrees in phase from the normal position for measuring power. In case of two-phase and three-phase circuits the reactive volt-amperes can be measured with a polyphase wattmeter, for it is possible in these circuits to select or produce the necessary voltages.

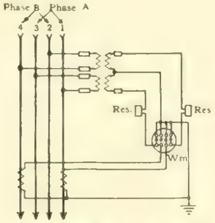

FIG. 72—MEASURING WATTLESS VOLT-AMPERES WITH A POLYPHASE WATTMETER

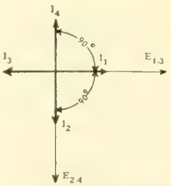

FIG. 73—BALANCED LOAD AT UNITY POWER-FACTOR

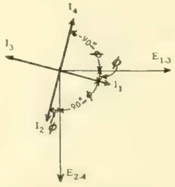

FIG. 74—BALANCED LOAD WITH LAGGING CURRENT AT ANY POWER-FACTOR

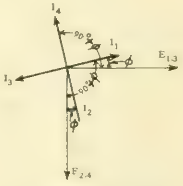

FIG. 75—BALANCED LOAD WITH LEADING CURRENT AT ANY POWER-FACTOR

The connections for measuring the reactive volt-amperes in a two-phase circuit with a polyphase wattmeter are shown in Fig. 72. Standard voltage and current transformers are used and the meter does not require special calibration. Since the voltages in the two phases are 90 degrees apart, it is only necessary to connect the current in one phase and the voltage of the other phase to each element respectively in order to get the correct phase relations between the voltages and currents for measuring reactive volt-amperes. A vector diagram for this circuit for a balanced load at unity power-factor is shown in Fig. 73. $E_{1\,3}$ and $E_{2\,4}$, 90 degrees apart, represent the voltages in the two phases and I_1, I_2, I_3 and I_4 represent the respective line currents. I_1 represents the current which flows through the right hand element of the wattmeter, since the current transformer is in line 1. $E_{2\,4}$, 90 degrees out of phase, is connected to the right hand element and therefore the measurement in this element is $E_{2\,4}\,I_1 \cos 90° = 0$. Likewise the measurement in the left hand element is $E_{1\,3}\,I_4 \cos 90° = 0$. Thus the meter registers zero reactive volt-amperes at unity power-factor, which is correct, since the current is in phase with the voltage and the volt-amperes are equal to the watts delivered by the circuit. The result is shown to be correct also from the general expression for the reactive volt-amperes in a two-phase circuit, $2\,EI \sin 0° = 0$.

In Fig. 74 is shown a vector diagram for the same circuit for a balanced load at any power-factor where the current lags by an angle ϕ. The measurement in the right-hand element W_R is $E_{2\,4}\,I_1 \cos (90° - \phi) = E_{2\,4}\,I_1 \sin \phi$ or, omitting the sub-figures, since $E_{2\,4}$ is equal to the line voltage E and I_1 is the line current, $W_R = EI \sin \phi$. The measurement in the left hand element is $E_{1\,3}\,I_4 \cos (90° - \phi) = E_{1\,3}\,I_4 \sin \phi$ or, omitting the sub-figures it becomes $EI \sin \phi$. The sum of the measurements in the two elements is $2\,EI \sin \phi$ which is correct. It can be seen from the vector diagram that if the angle of lag becomes 90 degrees, I_1 is in phase with $E_{2\,4}$ and I_4 is in phase with $E_{1\,3}$ and the measurement by the meter becomes $2\,EI \sin 90° = 2\,EI$. This represents full scale deflection on the meter, or in other words, all the volt-amperes in the circuit are reactive.

In Fig. 75 is shown a vector diagram for the same circuit for a balanced load at any power-factor where the current leads by an angle ϕ. The measurement in the right-hand element of the wattmeter is $E_{2\,4}\,I_1 \cos (90° + \phi) = -E_{2\,4}\,I_1 \sin \phi$. Omitting the sub-figures, since $E_{2\,4}$ is equal to the line voltage and I_1 is the line current, W_R becomes equal to $-EI \sin \phi$. Similarly the measurement in the left hand element is $E_{1\,3}\,I_4 \cos (90° + \phi) = -E_{1\,3}\,I_4 \sin \phi$ or $-EI \sin \phi$. The sum of the measurements in the two elements is $-2\,EI \sin \phi$ which is the same as the case of lagging current except that it is negative, that is, the deflection of the meter's pointer is in the opposite direction. It is therefore necessary for a wattmeter, which is to be used for measuring reactive volt-amperes, to be provided with a zero-center scale so that it may give full scale deflection in either direction. The meter thus connected not only gives a measurement of the reactive volt-amperes in the two-phase circuit but also indicates whether the current lags or leads by the deflection being in a positive or negative direction respectively. The deflection of a meter is considered positive when the pointer swings across the scale from left to right for horizontal scales, or in a clockwise direction for circular dials (when facing the front of the meter). Since an element of the wattmeter measures the reactive volt-amperes in each of the two phases respectively, the same as for two independent single-phase circuits, the measurement by the meter is correct for unbalanced as well as for balanced loads.

The Thermal Storage Demand Wattmeter

Its Characteristics and Application

Paul M. Lincoln

THE WIDE SPREAD use of central station rates involving a maximum demand charge, brings with it the necessity for means of determining the maximum demand which are accurate, relatively inexpensive, easy to read, and whose registration conforms as closely as possible to the temperature rise in the transformers and generators which supply the power. Various types of demand meters are in use, but these requirements are met most closely by the thermal type of instrument.

The principle upon which a thermal *ammeter* is based is fairly obvious, as the heat generated in a resistor is proportional to the square of the current, which can be measured by a single element. The indications of the thermal *wattmeter*, however, depend on the relative temperatures of two similar bodies, each of which is influenced by the resultant of two currents, one of which is proportional to the current in the circuit, while the other is proportional to the circuit voltage. The operation of the thermal wattmeter is shown diagrammatically* in Fig. 2, in which *A* is a single-phase circuit feeding a load *B*. A small transformer *C* is incorporated within the meter with its primary across the circuit *A*. In series with the secondary of this transformer are two equal resistances R_1 and R_2. A current is set up in these resistances proportional to the voltage of the circuit. The load current is also caused to circulate through these same resistances, as shown in Fig. 2, being taken in at the middle of the secondary of the small transformer and out at the connection between resistances R_1 and R_2. These two currents—one the secondary current, due to the presence of the voltage, and the other due to the passage of the load current—are additive in one of the resistances and subtractive in the other, and the difference in the heating effect of the two currents is proportional to the wattage of the load *B*. If the current that passes through the resistances R_1 and R_2, due to the presence of the voltage is represented by E, and the load current therein by I, the resultant current in one of these resistances is E plus $\frac{1}{2} I$, and in other E minus $\frac{1}{2} I$.

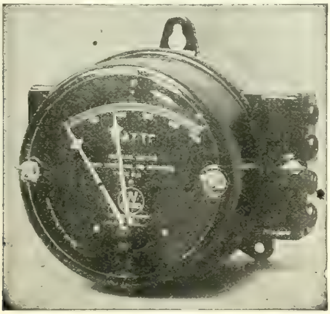

FIG. 1—POLYPHASE THERMAL DEMAND METER

Polyphase meters have a double set of heating elements, connected in the usual method for measuring polyphase power with two wattmeters. For single-phase, the two sets are connected either in series or parallel.

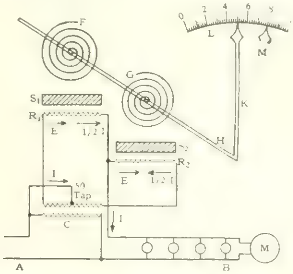

FIG. 2—SCHEMATIC DIAGRAM OF THERMAL DEMAND WATTMETER

Two spiral springs, *F* and *G*, made from bimetallic strips, are attached rigidly to their casings at the outer ends and to a common shaft *H* at their inner ends. These bimetallic springs tend to coil up with increase in temperature (due to the difference in temperature coefficient of the two metals of which they are composed) but, since the two springs are wound in opposite directions, no movement of the shaft *H* will take place unless there is a difference in temperature between *F* and *G*. The shaft *H*, therefore, will not turn with changes in atmospheric temperature or with any other condition that causes both springs to maintain the same temperature, but will respond only to the difference in temperature caused by the difference in the losses in resistances R_1 and R_2. S_1 and S_2 represent diagrammatically the thermal storage of the cases in which the bimetallic springs *F* and *G* are enclosed. Due to this thermal storage, the wattmeter does not respond instantly to a change in load, but always indicates the logarithmic average load over the time period immediately preceding the instant of observation, the length of this time period being determined in part by the amount of thermal storage of the cases. *K* is a pointer attached to shaft *H* and traveling over the scale *L*. *M* is a friction pointer which shows the highest position of pointer *K* since last reset.

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*The principle of operation of this meter is described fully in a paper by the author, Trans. A. I. E. E. Feb. 15, 1918., Vol. XXXVII, p. 189.

That the indications of such a device will correspond to the watts, independent of power-factor, is indicated graphically in Fig. 3. Suppose *AB*, Fig. 3, is the value of the current that flows through the resistances R_1 and R_2, due to the secondary voltage *E* in the transformer *C* of Fig. 2. Suppose further that *CD*, represents both in magnitude and phase angle the load current *I* that flows through these same resistances. It is obvious that the resultant current in resistance R_1 is proportional to the distance *AC* Fig. 3, and that in R_2 is proportional to *AD*. If *AB* and *CD* are in phase, the resultant currents are respectively $E + 1/2\ I$ and $E - 1/2\ I$. Since the heating effects are proportional to the squares of these values, the indication on the scale is proportional to $(E + 1/2\ I)^2 - (E - 1/2\ I)^2 = 2\ EI$. If *AB* and *CD* are 90 degrees out of phase with each other, it is obvious that the two resultants will always be of the same value. For any other angle, or for any wave shapes, it can be proved mathematically* that the watts are proportional to $AC^2 - AD^2$, and this is the value that is measured by the demand meter. The time element of the meter is dependent upon the heat storage capacity of the springs and their cases. It is defined as the time required for the meter to reach 90 percent of the value of a continuously applied load.

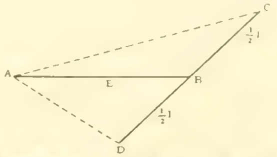

FIG. 3—VECTOR DIAGRAM OF CURRENT RELATIONS

The quantity measured by the thermal storage demand meter is the average watts over a certain time previous to the instant of observation, rather than the instantaneous watts as measured by an ordinary wattmeter. Further, the average, so measured, is not the arithmetical average, but what is called the "logarithmic" average. In other words, the indication of a thermal storage wattmeter is not that due to the watts passing at that instant, but is the resultant of all the wattage flow that has passed, each instant of past flow having a value influenced in respect to its time proximity by a logarithmic law. When the word average is used in its commonly accepted sense, it is assumed that each instant of time over which the average is taken has equal weight. In the resultant that is obtained by a heat storage meter, each instant of time has not an equal weight, but the influence of each instant decreases with its remoteness in point of time. The degree by which the watts during any instant influence the total indication is proportional to ϵ^{-kt} where ϵ is the base of the Napierian logarithms, *k* is an adjustable constant and *t* is the time measured backward from the instant of observation. If a steady load *W* is applied to the meter, the meter starting at zero, the theoretical reading of the meter after an application of the load *W* for *t* minutes is $W\left(1 - \epsilon^{-\frac{2.303t}{T}}\right)$, *T* being the period of the meter in minutes. For steady loads, the logarithmic and arithmetical averages are the same. The same is true where the load is fluctuating, provided the fluctuations in load are comparatively rapid. For instance, if the load fluctuations do not exceed two minutes in duration on a thirty minute meter, the results on the logarithmic and arithmetical average meters are the same.

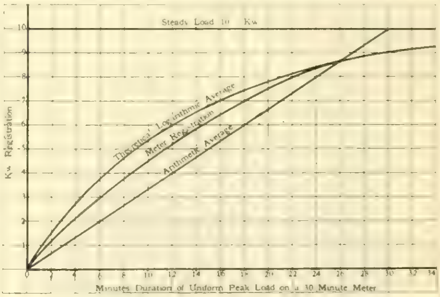

FIG. 4—COMPARISON OF THERMAL DEMAND METER REGISTRATION WITH ARITHMETIC AVERAGE OF LOAD

For isolated peaks of load of longer duration than two minutes, the logarithmetic average meter responds to the increment of load in excess of the previously existing steady load in a manner that will give results close to, but not necessarily indentical with the arithmetical average. In general, the logarthmic average meter will give results much closer to the arithmetical average maximum demand than will the standard "block interval" demand meters now in use for measuring maximum demand. For instance, the arithmetical average of an isolated peak load, for a time duration of more than about 26 minutes, will be less than the registration of a 30 minute thermal demand meter, the maximum value of the difference being ten percent of the increment of the peak load over the previously existing steady load, as shown in Fig. 4. For peak load durations less than about 26 minutes the arithmetic average will be less than the logarithmic

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*Such proof is given in Appendix II of a paper entitled "Rates and Rate Making" *Trans. A. I. E. E.*, October 8, 1915, Vol. XXXIV, p. 2313.

average registered by the thermal meter, the percentage difference increasing as the duration of peak load decreases, as showing in Fig. 4. For example, if a ten kw load is applied to a 30 minute thermal demand meter for five minutes, it will register—providing the previous load has been zero—about 2.64 kw of demand, while the arithmetical average of that same five minute peak over the 30 minute period would be 1.67 kw. If the peak should last for twenty minutes instead of five minutes, the thermal meter would register approximately 7.54 kw of demand as against 6.67 kw by the arithmetical meter. As indicated above, at about twenty-six minutes of load duration, the indications of both types of meter would be indentical. In brief, for a short time duration of the peak load, the arithmetical average is lower than the logarithmic average; for longer periods of time, the arithmetical average is slightly higher than the logarithmic average; while for very long durations, exceeding twice the time period of the meter, there is no appreciable difference. The logarithmic characteristic of the thermal demand meter is of advantage, because such a device recognizes the heating, and this is the quantity after all that should be recognized, since that is what fixes the limiting capacity of the equipment necessary to furnish the service.

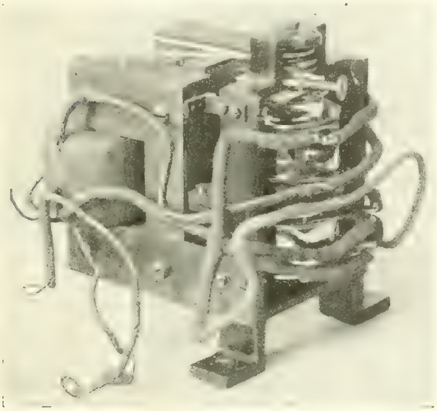

FIG. 5—SINGLE-PHASE METER ELEMENT

THE FIELD OF APPLICATION OF THE DEMAND METER

Few will deny that load factor ought to be recognized in any rate for the sale of electric service. Dr. John Hopkinson, as far back as 1883, was the first to suggest and urge the recognition of load factor in rates for service and so firmly did he impress his ideas on the industry that ever since any method recognizing maximum demand in the rate has been called the "Hopkinson" method.

The Hopkinson method however, is a generic and not a specific term. There are many varieties of Hopkinson methods. The inherent complexity of the rate question, together with the long absence of any adequate method of measuring maximum demand, has led in many cases to the practice of inferring the maximum demand instead of measuring it. In some cases, for instance, it is the practice to base the maximum demand on the summation of all the name plate ratings of the motors connected. There are many objections to this practice. In the first place, it tends towards the installation of motors too small for their work, with consequent motor trouble. Next, it makes for the misbranding of motors in placing name plates on them smaller than their actual capacity. Motor manufacturers are often asked to alter name plates for the purpose of its influence on the prospective customers power bill. Next, it discourages individual drive for motor-driven appliances. Individual drive is coming to be recognized as the best practice and it is unfortunate, to say the least, that we should have another influence running counter. Next, it is coming to be the practice of guaranteeing no overloads on motors and here again this practice runs counter to that of basing maximum demand on name plate ratings. Again, this practice recognizes motors only, and in this day of electric furnaces, heating devices and the many other methods of using electric service, a method of inferring maximum demand that rests on the name plate rating of motors is deficient. Finally, it is not a users potentiality to use power that should fix his maximum demand, but his actual use. Maximum demand should be measured, not inferred.

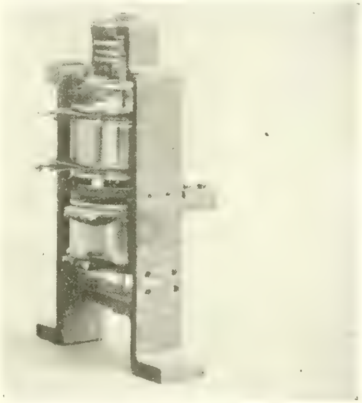

FIG. 6—BIMETALLIC SPRINGS AND THERMAL STORAGE CASES

There have been a number of attempts to build a suitable demand meter. Apparently the first of these was the Wright ampere demand meter brought out nearly 25 years ago. This device did not prove entirely satisfactory because it was an ammeter and not a wattmeter and was not very accurate. Unquestionably, the main reason for the absence of accuracy was that there was no method for compensating for the heat that flowed by conduction into or out of the lead wires. This device has had a considerable vogue in some sections in the past, but at present it is little used.

By far the largest group of maximum demand meters is based on the so called Merz principle, in which the advance of a standard watthour meter during a definite time interval is obtained and the largest one of these is recorded. The inherent disadvantage of this type is that it may split the peak. The maximum error due to this splitting is 50 percent, but the device has the advantage that the error is always one of under-registration and it cannot over-register, if operating normally. In addition to a watthour meter, the Merz demand meter requires some sort of a clock or timing device, and the mechanism for obtaining and recording the values of the integrating meter during the successive time period is somewhat complex and apt to give trouble. The simplicity of the thermal type of demand meter, coupled with the fact that its indications always respond to the true thermal effect of the average watt consumption over a definite preceding time period, gives that type a very decided advantage.

The thermal type of meter is now available for a number of time periods, such as 15 and 30 minute intervals. Longer time periods can easily be produced if the demand for them arises. The essential difference between various time periods is in the mass of material attached to the heaters. The difference in time periods rests on the simple principle that a large mass of material takes longer to heat than does a smaller mass. In the very short time meters, the parts enclosing the heater and which compose the metallic box enclosing the bimetallic springs is made of material which is about as light as will make a good substantial device. By eliminating the enclosing box entirely, and passing the currents directly through the bimetallic springs, time periods as low as about one minute have been secured experimentally. However, there are serious objections to this construction.

There is another consideration that raises a question as to the real need for time periods of less than those now commercially available and this is that there is practically no electrical equipment with an inherent time period of its own of less than ten minutes. A standard ten horse-power motor, for instance, requires about an hour for its copper to attain 90 percent of its final temperature rise and for the iron parts this time increases to about one and a half hours. For smaller equipment, the natural time periods decrease and for larger equipment, the time periods increase. In the case of a very large self-cooled transformer—about 5000 kv-a capacity—the time required to attain 90 percent of its final temperature rise was over 24 hours. From these examples, it is obvious that the inherent characteristics of electrical equipment do not indicate the necessity of time periods in demand meters of less than the ten minutes now available.

The time periods of demand in use at the present time vary all the way from one minute as a minimum to one hour as a maximum. There are very few places where time periods of demand as short as one minute are used and in some of these cases the time period of the maximum demand was fixed not by the consideration of the heating of the electrical equipment but on the theory that the water wheels—they were water power plants—had no excess capacity over and above their rating. It would seem that this consideration would lead to an instantaneous peak rather than a one minute peak. A further fallacy in this logic is that the only consideration involved is the over-load capacity of the prime mover and that no consideration is given the generators, transformers, transmission lines, distribution systems, etc. necessary in the complete installation. If the entire capacity of a plant were to be supplied to a single customer, the one minute demand basis would be more logical, but under the actual conditions of supply in a typical case, where any single customer forms only a small part of the total demand on the station, it is the limiting capacity of the equipment installed for a given customer that should govern the time period of his maximum demand. The characteristics of such equipment will certainly dictate that time periods of not less than 10 minutes should be used and it is the writer's opinion that time periods of 30 minutes or perhaps even longer would be even more logical.

There are certain other phases of the general metering problem that demand prior attention. One of these auxiliary phases of the metering question is the need of some method of recognizing the kv-a. of demand rather than the kw. It is kv-a. rather than kw that causes the heating in generators, transformers and distribution lines. The use of the amperes of demand instead of the kw tends to recognize kv-a. instead of kw, but it has the fatal defect that a low voltage—for which the customer is not responsible—will increase the current and thus the customer will be penalized for a condition for which he is not responsible. There are several methods of measuring the demand in kv-a at present but all of them open to serious objection. One method sometimes used is to install both a graphic wattmeter and a graphic power-factor meter. This is not very satisfactory, since it requires the integration of the wattmeter chart and in addition the use of a factor obtained from the power-factor meter to reduce the watts of demand to the volt-amperes of demand. The first of these difficulties may be avoided by using a graphic demand wattmeter instead of one of the usual type and this, in conjunction with the graphic power-factor meter, can be used to determine the kv-a. Instead of the power-factor meter, a reactive component meter may be used, and its indications combined with the wattmeter to obtain kv-a. This method has the advantage of using duplicate meters for kw and reactive kv-a, the only difference being in the method of connection. Until there is some method of making this combination mechanically within the meter itself, the use of two separate meters and making the combination externally must suffice. Up to the present time it has undoubtedly formed the best method of securing the kv-a. of demand, but improvements are due.

Electrical Characteristics of Transmission Circuits-X

Performance of Long Transmission Lines
(A Review of Hyperbolic Trigonometry)

Wm. Nesbit

In the consideration of the hyperbolic theory as applied to transmission circuits, the writer desires to express his high appreciation of the excellent literature already existing. Dr. A. E. Kennelly's pioneer work and advocacy of the application of hyperbolic functions to the solution of transmission circuits has been too extensive and well known to warrant a complete list of his contributions. His most important treatises are "Hyperbolic Functions Applied to Electrical Engineering", 1916; "Tables of Complex Hyperbolic and Circular Functions", 1914; "Chart Atlas of Hyperbolic Functions", 1914, which provides a ready means of obtaining values for complex functions, thus materially shortening and simplifying calculations, and "Artificial Electric Lines", 1917.

"Electrical Phenomena in Parallel Conductors" by Dr. Frederick Eugene Pernot, 1918, is an excellent treatise on the subject and contains valuable tables of logarithms of real hyperbolic functions from $x = 0$ to $x = 2.00$ in steps of 0.001.

An article "Long-Line Phenomena and Vector Locus Diagrams" in the *Electrical World* of Feb. 1, 1919, p. 212, by Prof. Edy Velander is an excellent and valuable contribution on the subject, because of its simplicity in explaining complicated phenomena.

To employ hyperbolic functions successfully in the solution of transmission circuits it is not necessary for the worker to have a thorough understanding of how they have been derived. On the other hand it is quite desirable to understand the basis upon which they have been computed. A brief review of hyperbolic trigonometry is therefore given before taking up the solution of circuits.

Circular angles derive their name from the fact that they are functions of the circle, whose equation is $x^2 + y^2 = 1$. Tabulated values of such functions are based upon a radius of unit length. The geometrical construction illustrating three of the functions, the sine, cosine and tangent of circular angles is indicated in Fig. 38. The angle *AOP*, indicated by full lines in the positive or counter-clockwise direction, has been drawn to correspond to one radian. The radian is an angular unit of such magnitude that the length of the arc which subtends the radian is numerically equal to that of the radius of the circle. Thus, the number of radians in a complete circle is 2π. Expressed in degrees the radian is equal approximately to 57° 17′ 44.8″. The segment *AOP* of any angle *AOP* of one radian has an area equal to one-half the area of a unit square. Therefore the angle may be expressed in radians as,—

$$\frac{Length\ of\ arc}{radius} \quad or \quad \frac{2 \times area}{(radius)^2}$$

Circular functions are obtained as follows,—

$$Circular\ angle = \frac{2 \times area}{(radius)^2}\ radians$$

$$Sine\ \theta = \frac{Y}{R}$$

$$Cosine\ \theta = \frac{X}{R}$$

$$Tangent\ \theta = \frac{Y}{X}$$

The variations in the circular functions, sine, cosine and tangent are indicated graphically in Fig. 39 for a complete revolution of 360 degrees. Since for the second and each succeeding revolution these graphs would simply be repeated, circular functions are said to have a period equal to 2π radians. In other words, adding 2π to a circular angle expressed in radians does not change the value of a circular function.

REAL HYPERBOLIC ANGLES

Real hyperbolic angles derive their name because they are functions of an equilateral hyperbola. A hyperbola is a plane curve, such that the difference between the distances from any point on the curve to two fixed points called the foci is constant. In an equilateral hyperbola, Fig. 40, the asymptotes *OS* and *OS′* are straight lines at right angles to each other and make equal angles with the X-axis. The hyperbola continually approaches the asymptotes, and meets them at infinity. The equation of such a hyperbola is $x^2 - y^2 = 1$.

The hyperbolic angle *AOP* of Fig. 40, called for convenience θ*, has been drawn so as to correspond to an angle of one hyperbolic radian, or one "hyp" as it is usually designated. Hyperbolic angles are determined by the area of the sector they enclose. Thus the hyperbolic angle of one hyp *AOP*, encloses an area *AOP* of one-half, or the same as the area *AOP* of the corresponding circular angle of Fig. 38. It should be observed here that although one circular radian subtends an angle *AOP* of 57° 17′ 44.8″, one hyperbolic radian subtends a circular angle *AOP* of 37° 17′ 33.67″ (0.65087 circular radian).

In the same way as for the circle the hyperbolic angle may be expressed in radians as,—

$$\frac{Length\ of\ arc}{\rho} \quad or \quad \frac{2 \times area}{(radius)^2}$$

where ρ = the integrated mean radius from *O* to *AP*. As an illustration, the length of the arc *AP*, Fig. 40

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*A "hyperbolic angle", in the sense above described, is not the opening between two lines intersecting in a plane, but a quantity otherwise analogous to a circular angle and the argument x of the function *sinh x*, *cosh x*, *tanh x*, etc. The use of the term hyperbolic angle can only be justified by its convenience of anology.

is 1.3167 and the mean integrated radius to arc *AP* is 1.3167.

Hyperbolic functions, distinguished from circular functions by the letter *h* affixed, are obtained as follows:—

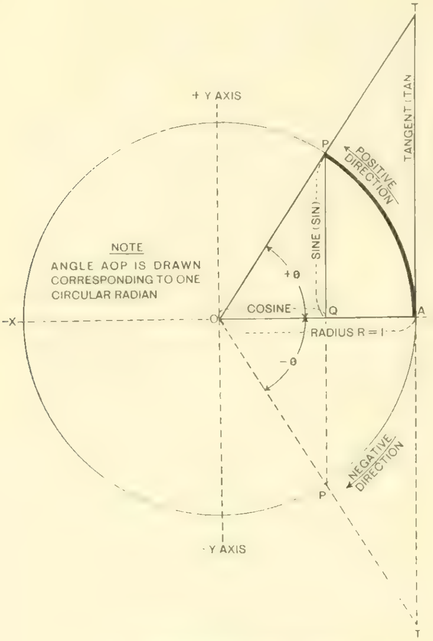


FIG. 38—REAL CIRCULAR ANGLES

$X^2 + Y^2 = 1$

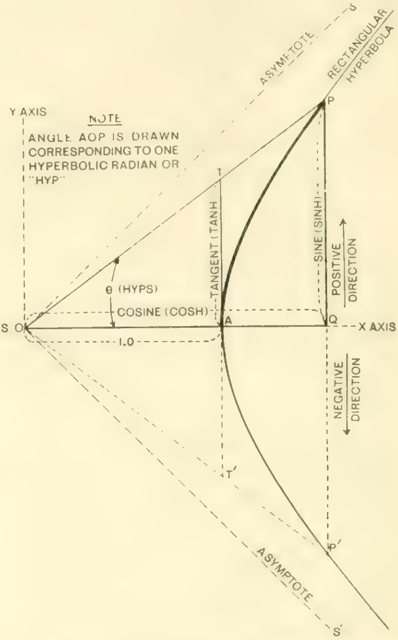


FIG. 40—REAL HYPERBOLIC ANGLES

$X^2 - Y^2 = 1$

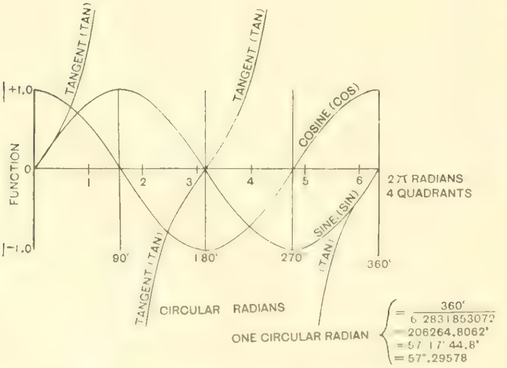


FIG. 39—GRAPHS OF CIRCULAR FUNCTIONS

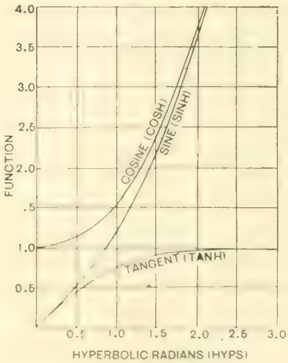


FIG. 41—GRAPHS OF HYPERBOLIC FUNCTIONS

$$\text{Hyperbolic angle } \theta = \frac{\text{Length of arc } AP}{\text{Length of mean radius}} \text{ radians}$$

$$\text{Cosh } \theta = \frac{X}{OA}$$

$$\text{Sinh } \theta = \frac{Y}{OA}$$

$$\text{Tanh } \theta = \frac{Y}{X}$$

The variations in hyperbolic functions are indicated graphically in Fig. 41 for hyperbolic angles up to approximately 2.0 hyps for the sine and cosine and up to 3.0 hyps for the tangent.

Hyperbolic functions have no true period, but adding a $2\pi j$ to the hyperbolic angle does not change the values of the functions, hence these functions have an imaginary period of $2\pi j$.

Circular functions can be used to express the phase relations of current and voltage, but not the magnitude, or size, whereas hyperbolic functions, continually increasing or decreasing, can be used to express the magnitude of current in a long circuit.

In Fig. 42 is shown a circular angle corresponding to one circular radian divided into five equal parts, each of 0.2 radian. Assuming unity radius, each of the arcs will have a constant length of 0.2 and a constant mean radius of 1.0. In Fig. 42 is shown a hyperbolic angle corresponding to one hyperbolic radian divided into five equal hyperbolic angles each of 0.2 hyperbolic radian. In this case the length of the arcs corresponding to each subdivision increases as the hyperbolic angle increases. The lengths of the corresponding integrated mean radii vectors also increase with the angle. By dividing the length of the arc of any of the five subdivisions by the length of the mean radius for that subdivision it will be seen that each subdivision represents 0.2 hyps.

From the above it will be evident that in radian measure, the magnitudes of circular and hyperbolic angles are similarly defined with reference to the area of circular and hyperbolic sectors.

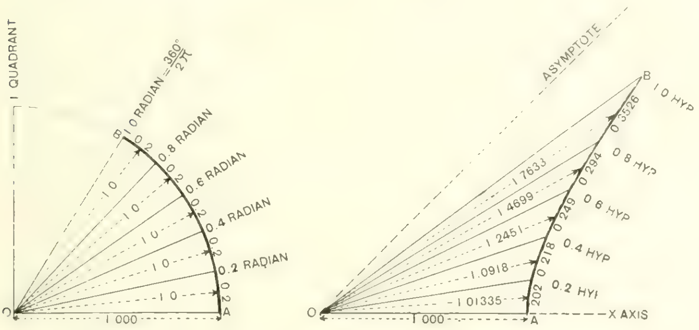


FIG. 42—SUBDIVISION OF A CIRCULAR AND A HYPERBOLIC RADIAN INTO FIVE SECTORS OF 0.2 RADIAN EACH

ADDITIONAL SYMBOLS

In addition to the symbols previously listed, the following will be employed in the hyperbolic treatment.

α = Linear hyperbolic angle expressed in hyps per mile. It is a complex quantity consisting of a real component α_1 and an imaginary component α_2. It is also known as the attenuation constant or the propagation constant of the circuit.

α_1 = The real component of the linear hyperbolic angle α, expressed in hyps. It is a measure of the shrinkage or loss in amplitude of the traveling wave, per unit length of line traversed.

α_2 = The imaginary component of the linear hyperbolic angle α, expressed in circular radians. It is a measure of the loss in phase angle of the traveling wave, per unit length of line traversed.

θ = The complex hyperbolic angle subtended by the entire circuit, expressed in hyps. It differs from α in that it embraces the entire circuit, whereas α embraces unit length of circuit (in this case one mile), $\theta = \alpha \times L$, where L is the length of the circuit expressed in miles.

θ_1 = The real component of the complex hyperbolic angle of the circuit expressed in hyps, and defines the shrinkage or loss in amplitude or size of a traveling wave, in traversing the whole length of the line.

θ_2 = The imaginary component of the complex hyperbolic angle of the circuit expressed in circular radians, expressing the loss in phase angle or slope of the traveling wave, in traversing the whole length of line.

= 2.7182818 which is the base of the Napierian system of logarithms. Log_{10} = 0.4342945.

θ_s = Position angle at sending end.

θ_r = Position angle at receiving end.

θ_p = Position angle at point P on a circuit.

δ = Impedance load to ground or zero potential at receiving end line, in ohms at an angle.

$z_0 = \sqrt{\frac{z}{y}}$ = Surge impedance of a conductor in ohms at an angle.

$y_0 = \frac{1}{z_0}$ = Surge admittance of a conductor in mhos at an angle.

COMPLEX ANGLES AND THEIR FUNCTIONS

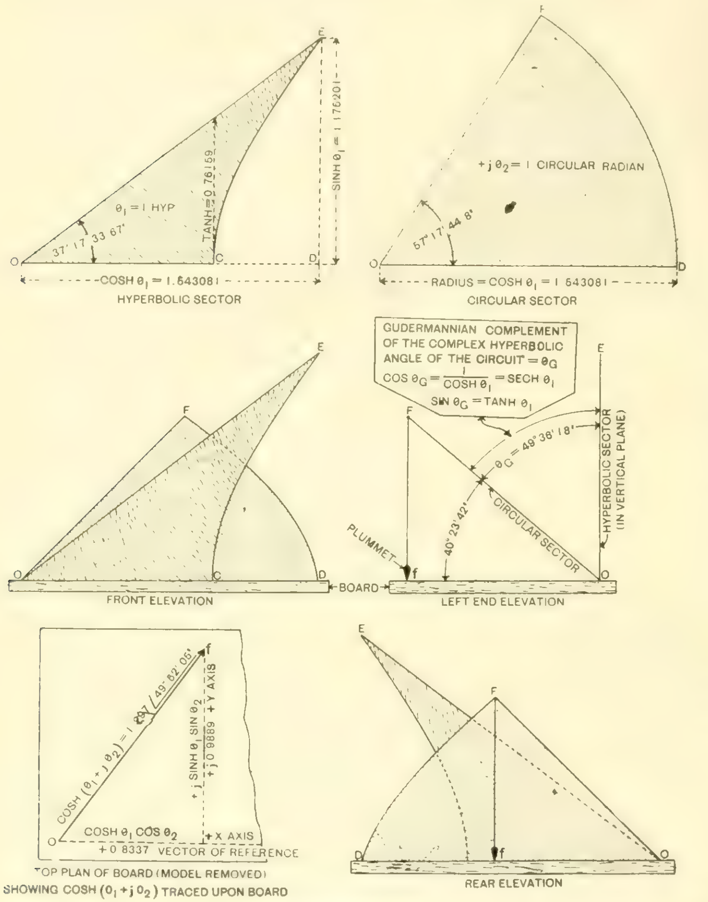
A complex angle is one which is associated with both a hyperbolic and a circular sector. If the complex angle is hyperbolic, its real part relates to a hyperbolic and its imaginary part to a circular sector. On the other hand, if the complex angle is circular, its real part relates to a circular and its imaginary part to a hyperbolic sector. Complex hyperbolic trigonometry and complex circular trigonometry thus unite in a common geometrical relationship.

In the following treatment for the solution of transmission circuits by hyperbolic functions, only hyperbolic complex angles will enter into the solution. Such a complex angle will then consist of a combination of a "real" hyperbolic sector and a so-called "imaginary" or circular sector. The circular sector will occupy a plane inclined at an angle to the plane of the hyperbolic sector. In other words, the complex angle will be of the three-dimensional order. The construction of such a complex angle may be difficult to follow if viewed only from one direction. In order to illustrate the form that a complex angle takes, the construction for the cosine of a hyperbolic complex angle is illustrated by Fig. 43.

CONSTRUCTION FOR COSH θ

The construction, Fig. 43, assumes that the real part, that is the hyperbolic sector subtends an angle of one hyperbolic radian and the imaginary part, that is the circular sector, subtends an angle of one circular radian. This hyperbolic complex angle has therefore a numerical value of $1 + j\,1$ hyperbolic radian. These numerical values embrace sectors sufficiently large for the purpose of clear illustration. The actual construction for obtaining the complex function cosh $(\theta_1 + j\,\theta_2)$ = cosh $(1 + j\,1$ hyperbolic radians) may be carried out as follows:—

On a piece of stiff card board lay out to a suitable scale the hyperbolic sector $\theta_1 = EOC$, equal to one hyp as shown in the upper left hand corner of Fig. 43. This may readily be plotted by the aid of a table of real hyperbolic functions for say each one tenth of a hyp up to and including one hyp. These are then plotted on the cardboard and joined with a curved line thus forming the arc *EC* of Fig. 43. The ends of the arc are then joined with *O* by straight lines. The real part of this hyperbolic complex angle is then cut out of the cardboard.


E
C
D
O
TANH = 0.76159
SINH θ1 = 1.176201
θ1 = 1 HYP
37° 17' 33.67'
COSH θ1 = 1.643081
HYPERBOLIC SECTOR
F
+j θ2 = 1 CIRCULAR RADIAN
57° 17' 44.8'
RADIUS = COSH θ1 = 1.643081
CIRCULAR SECTOR
FRONT ELEVATION
BOARD
GUDERMANNIAN COMPLEMENT OF THE COMPLEX HYPERBOLIC ANGLE OF THE CIRCUIT = θG
COS θG = 1/COSH θ1 = SECH θ1
SIN θG = TANH θ1
θG = 49° 36' 18'
40° 23' 42'
CIRCULAR SECTOR
HYPERBOLIC SECTOR (IN VERTICAL PLANE)
PLUMMET
f
LEFT END ELEVATION
COSH (θ1 + j θ2) = 1.297 /49° 52' 05'
+j SINH θ1 SIN θ2
+j 0.9889 + Y AXIS
COSH θ1 COS θ2
+ X AXIS
+0.8337 VECTOR OF REFERENCE
TOP PLAN OF BOARD (MODEL REMOVED) SHOWING COSH (θ1 + j θ2) TRACED UPON BOARD
REAR ELEVATION

MATHEMATICAL SOLUTION

$$\cosh(\theta_1 + j\theta_2) = (\cosh\theta_1 \cos\theta_2 + j \sinh\theta_1 \sin\theta_2)$$

LOG COSH $\theta_1 = 0.188,389$ LOG SINH $\theta_1 = 0.070,112$

LOG COS $\theta_2 = \bar{1}.732,636$ LOG SIN $\theta_2 = \bar{1}.925,039$

$\bar{1}.921,026$ $\bar{1}.995,151$

$$\cosh(\theta_1 + j\theta_2) = 0.8337 + j\,0.9889$$
$$= 1.297 \angle 49^\circ 52' 05'$$

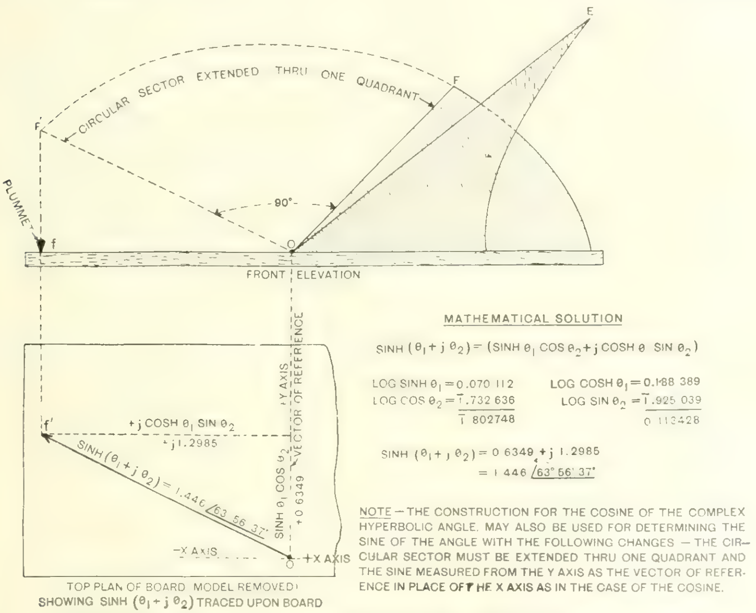
FIG. 43 GRAPHICAL CONSTRUCTION FOR THE HYPERBOLIC COSINE OF THE COMPLEX ANGLE $\theta_1 + j\theta_2 = 1 + j1$ Hyperbolic Radians.

The circular part $j\,\theta_2$ of this complex angle is traced upon the cardboard as follows:—With radius equal to cosh θ_1 (to the same scale as used when tracing the hyperbolic sector θ_1) draw the arc *DOF* of a length such that the angle *DOF* is 57° 17′ 44.8″ (one circular radian). Join the ends of the arc to *O* with straight lines. The circular part $j\,\theta_2$ of this complex angle is now cut out of the piece of cardboard. This gives models of the two parts of the complex angle which may be arranged to form the complex angle $1 + j\,1$ hyps. These two models are shown at the top of Fig. 43.

The two parts of the complex angle are arranged as follows:—Upon a drawing board or any flat surface occupying a horizontal plane, place the hyperbolic sector θ_1 in a vertical position. The plane of this hyperbolic sector will then be at right angles to the plane of the drawing board. The circular sector $j\,\theta_2$ is now placed in a vertical position just back of the hyperbolic sector. The toes *O* of each sector will then coincide, as well as the line *OD* of the circular sector with the line *OC* of the hyperbolic sector. The top of the circular sector is now turned back so that the plane of the circular sector lies at an angle with the vertical plane occupied by the hyperbolic sector. This displacement angle between the planes of the two sectors is known as the "gudermannian complement" of the hyperbolic angle θ. It will be referred to as θ_G. The front elevation of Fig. 43 illustrates how these two sectors would appear when viewed from the front. To the right of this illustration is shown how these two sectors would appear when viewed from the left hand end of the model. The displacement angle θ_G has a value for this particular complex angle of 49° 36′ 18″. This numerical value is determined by virtue of the fact that this displacement angle has a cosine of $\frac{1}{\cosh\theta_1} = \frac{1}{1.543081} = 0.64805$ or cosine of $\theta_g = \text{sech}\,\theta_1 = 0.64805$. It has a sine of $\tanh\theta_1 = 0.76159$.

The angle whose cosine is 0.64805 and whose sine is 0.76159 is 49° 36′ 18″. Thus the top part of the circular sector of this complex angle is moved in the forward direction through an angle of 49° 36′ 18″ so that the plane of the circular sector assumes an angle of 90° 00′ 00″ — 49° 36′ 18″ = 40° 23′ 42″ with the horizontal plane of the drawing board. From the end of the circular sector (point F) thus inclined, a plummet may be suspended until it meets the horizontal plane of the drawing board at the point f of the illustration. In other words, the point F is projected orthogonally onto the horizontal plane of the drawing board.

A top view of the drawing board, with the model removed, is illustrated in the lower left hand corner of Fig. 43. The line OF ($1.297\ /49° 52' 05''$) traced upon the horizontal drawing board, is a vector representing the complex cosine of the complex angle $\theta_1 + j\,\theta_2 = 1 + j\,1$ hyperbolic radians. This complex cosine has rectangular co-ordinates of $+\ 0.8337$ and $+\ j\ 0.9889$.


E
F
F′
CIRCULAR SECTOR EXTENDED THRU ONE QUADRANT
PLUMMET
f
-90°-
O
FRONT ELEVATION
f′
+j COSH θ1 SIN θ2
+j 1.2985
SINH (θ1+j θ2) = 1.446 /63 56 37
SINH θ1 COS θ2
+0 6349
Y AXIS VECTOR OF REFERENCE
−X AXIS
+X AXIS
O
TOP PLAN OF BOARD MODEL REMOVED
SHOWING SINH (θ1 + j θ2) TRACED UPON BOARD

MATHEMATICAL SOLUTION

$$\text{SINH}(\theta_1 + j\,\theta_2) = (\text{SINH}\,\theta_1\,\text{COS}\,\theta_2 + j\,\text{COSH}\,\theta\ \ \text{SIN}\,\theta_2)$$

$$\begin{array}{lll} \text{LOG SINH}\,\theta_1 = 0.070\ 112 & & \text{LOG COSH}\,\theta_1 = 0.188\ 389 \\ \text{LOG COS}\,\theta_2 = \bar{1}.732\ 636 & & \text{LOG SIN}\,\theta_2 = \bar{1}.925\ 039 \\ \bar{1}\ 802748 & & 0\ 113428 \end{array}$$

$$\text{SINH}(\theta_1 + j\,\theta_2) = 0\ 6349 + j\ 1.2985$$
$$= 1\ 446\ \underline{/63° 56' 37''}$$

NOTE — THE CONSTRUCTION FOR THE COSINE OF THE COMPLEX HYPERBOLIC ANGLE. MAY ALSO BE USED FOR DETERMINING THE SINE OF THE ANGLE WITH THE FOLLOWING CHANGES — THE CIRCULAR SECTOR MUST BE EXTENDED THRU ONE QUADRANT AND THE SINE MEASURED FROM THE Y AXIS AS THE VECTOR OF REFERENCE IN PLACE OF THE X AXIS AS IN THE CASE OF THE COSINE.

FIG. 44—GRAPHICAL CONSTRUCTION FOR THE HYPERBOLIC SINE OF THE COMPLEX ANGLE $\theta_1 + j\theta_2 = 1 + j1$ hyperbolic radians.

At the bottom of Fig. 43 is given the mathematical expression for the exact solution for the cosine of a complex hyperbolic angle following the construction illustrated. There are numerous other mathematical equations with their equivalent geometrical constructions which will produce the same values for the cosine, but the above is probably as easy to follow as any, and will therefore be used exclusively hereafter.

CONSTRUCTION FOR SINH θ

The construction for the sine of the complex hyperbolic angle $1 + j\ 1$ is indicated in Fig. 44. In this case the same construction may be used for obtaining the sinh as for determining the cosh of the complex angle with the following two exceptions.

The circular sector is made one quadrant (90°) larger. In other words the angle DOF' is 90° + 57° 17′ 44.8″ or 147° 17′ 44.8″ as indicated by Fig. 44. It occupies the same plane as when determining the cosh of the angle but is simply extended in the forward direction through one quadrant, as indicated by the dotted lines of Fig. 44. The plummet is again suspended, this time from point F' upon the horizontal board, which it meets at point f'. The other difference is that the sine OF' is read off from the Y axis as the vector of reference in place of the X axis as in the case of the cosine. Thus the circular sector has been carried forward through an angle of 90 degrees in the circular angle plane and the vector of reference has been advanced 90 degrees in the horizontal plane of reference. The sine of this angle is $1.446\ /63° 56' 37''$ and has rectangular components of $0.6349 + j1.2985$. The mathematical expression for exact solution for the sine of a complex angle likewise accompanies the illustrated geometrical construction.

MODEL FOR ILLUSTRATING THE FUNCTIONS OF A COMPLEX ANGLE

Dr. Kennelly has recently constructed a model* for illustrating complex angles and for obtaining approximate values for the functions of such angles. Drawings made from photographs of this model are shown in Figs. 45, 46 and 47. The construction of a complex angle as above described is that employed by Dr. Kennelly in building his model. Since the model is applicable to tracing out numerous complex angles, it may seem a little difficult at the start. It was therefore thought desirable to precede the description of the model which is applicable to the solution of so many angles with a similar solution of a single definite complex angle. With the procedure for the solution, as given above, for cosh and sinh of $1 + j\ 1$ hyperbolic radians in mind, it is believed that Dr. Kennelly's description of the model and its application in determining the cosh and sinh of complex angles may be followed as given in the following paragraphs.

DESCRIPTION OF MODEL

In this model, the cosine or sine of a complex angle, either hyperbolic or circular, can be produced, by two successive orthogonal projections onto the *XY* plane, one projection being made from a rectangular hyperbola, and the other projection being then made from a particular circle definitely selected from among a theoretically infinite number of such circles, all concentric at the origin *O*, which circles, however, are not coplanar. The selection of the particular circle is determined by the foot of the projection from the hyperbola. This effects a geometrical process which is easily apprehended and visualized; so that once it has been realized by the student, the three-dimensional artifice is rendered superfluous, and he can roughly trace out a complex sine or cosine on an imaginary drawing board, with his eyes closed. The model, however, possesses certain interesting geometrical properties as a three-dimensional structure.

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*This model was described in a paper read by him at a meeting of the American Academy of Arts and Sciences in April 1916.

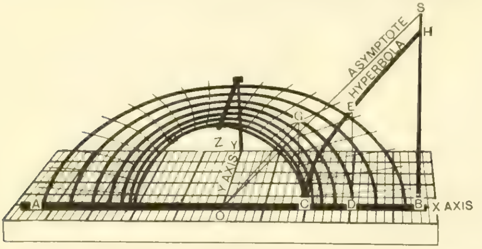


FIG. 45—DRAWING FROM A PHOTOGRAPH OF A GEOMETRICAL MODEL

For the orthogonal projection of the sines and cosines of complex angles. This model was developed by A. E. Kennelly.

A drawing made from a photograph of the model is shown in Fig. 45. On an ordinary horizontal drawing board 53.5 by 31.8 cm., is a horizontal rod *A B*, which merely serves to support the various brass-wire semicircles, and a semihyperbola, in their proper positions. The axis of *A B* in the *X Y* plane, on the upper surface of the board, is a line of symmetry for the structure, which, if completed, would be formed by full circles and a complete hyperbola. For convenience, however, only the half of the structure above the *X Y* plane is presented, the omission of the lower half being readily compensated for in the imagination.

The eight wire semicircles are formed with the following respective radii, in decimeters: 1.0, 1.020..., 1.081..., 1.185..., 1.337..., 1.543..., 1.810..., and 2.150..., which are the respective cosines of 0, 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, and 1.4 hyperbolic radians, according to ordinary tables of real hyperbolic functions. These successive semi-circles therefore have radii equal to the cosines of successively increasing real hyperbolic angles θ_1, by steps of 0.2, from 0 to 1.4 hyperbolic radians, inclusive. All of these semicircles have their common center at the origin *O*, in the plane *X O Y*, of the drawing board. The planes of the semicircles are, however, displaced. The smallest circle of unit radius (1 decimeter), occupies the vertical plane *X O Z*, in which [illegible] lies the rectangular semi hyperbola *X O H*. Angular distances corresponding to 0.2, 0.4,.... 1.4 hyperbolic radians, are marked off along this hyperbola at successive corresponding intervals of 0.2. The cosines of these angles, as obtainable projectively on the *O X* axis are marked off between *C* and *B* along the brass supporting bar, and at each mark, a semicircle rises from the *X Y* plane, at a certain angle θ_G with the vertical *X O Z* plane. This displacement angle is determined by the relation,—

$$\cos \theta_G = \frac{1}{\cosh \theta_1} = \operatorname{sech} \theta_1$$

Where θ_1 is the particular hyperbolic angle selected. This means, as is well known, that the displacement angle θ_G between the plane of any semicircle and the vertical plane *Z O X* is equal to the gudermannian of the hyperbolic angle θ_1.

The model is, of course, only a skeleton structure of eight stages. If it could be completely developed, the number of semicircles would become infinite, and they would form a smooth continuous surface in three dimensions. Along the midplane *Z O Y*, all of these circles would have the same level, raised one decimeter above the horizontal drawing board plane of reference *X O Y*. The circles would increase in radius without limit, and would cover the entire *X O Y* plane to infinity, the hyperbola extending likewise to infinity towards its asymptote *O S*, in the *X O Z* plane. The actual model is thus the skeleton of the upper central sheet of the entire theoretical surface, near the origin.

The semicircles are also marked off in uniform steps of circular angle. Each step is taken, for convenience, as nine degrees, or one tenth of a quadrant. Corresponding angular steps on all of the eight semicircles are connected by thin wires, as shown in the illustrations.

A front elevation of the model, taken from a point on the *O Y* axis—15 units from *O*, is given in Fig. 46. It will be seen that any tie wire, connecting corresponding circular angular points on the semicircles, is level, and lies at a constant height sin θ_2 decimeters above the drawing board. That is, the tie wire that connects all points of circular angle θ_2, measured from *O X* positively towards *OY*, lies at the uniform height sin θ_2 decimeters above the drawing board.

A plan view of the model, taken from a point on the *O Z* axis, + 15 units above *O*, is given in Fig. 47. It will be seen that each semicircle forms an ellipse, when projected on the base plane *X O Y*. The semi-major axis of this ellipse has length cosh θ_1, where θ_1 is the hyperbolic angle corresponding to that semicircle. The semi-minor axis is,—

$$\cosh \theta_1 \sin \theta_G = \cosh \theta_1 \tanh \theta_1 = \sinh \theta_1$$

from the well known relation that exists between a hyperbolic angle and its gudermannian circular angle; namely,—

$$\sin \theta_G = \tanh \theta_1$$

All of these ellipses have the same center of reference *O*. Any such system, having semi-major axes cosh θ_1, and semi-minor axes sinh θ_1, are well known to be confocal, and the foci must lie at the points +1 and —1 in the *X O Y* plane, or the points in which the innermost circle cuts that plane.

PROCEDURE FOR PROJECTING COSH ($\theta_1 + j\theta_2$)

Thus premised, the process of finding the cosine of a complex hyperbolic angle $\theta_1 + j\theta_2$; that is, the process of finding cosh $(\theta_1 + j\theta_2)$ is as follows:

Find the arc *C E*, Fig. 45, from *C* = +1 along the rectangular hyperbola *C E H*, which subtends θ_1 radians. The hyperbolic sector comprised between the radius, *O C*, the hyperbolic arc, and the radius vector *O E*, on this arc from the origin *O*, will then include $\frac{\theta_1}{2}$ sq. dm. of area. Drop a vertical perpendicular from *E* onto *O X*. It will mark off a horizontal distance *O D* equal to cosh θ_1. Proceed along the circle which rises at *D*, in a positive or counterclockwise direction, through θ_2 circular radians, thus reaching on that circle a point *G* whose elevation above the drawing board is sin θ_2 decimeters. The area enclosed by a radius vector from the origin *O* on the circle,

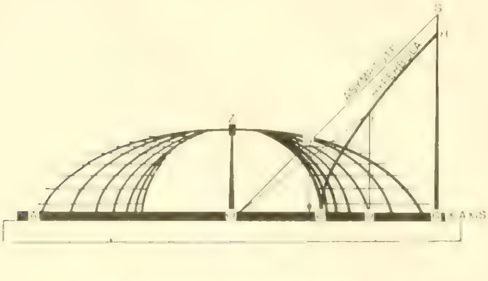


FIG. 46—FRONT ELEVATION OF MODEL

From a point on the *O Y* axis, — 15 units from *O*.

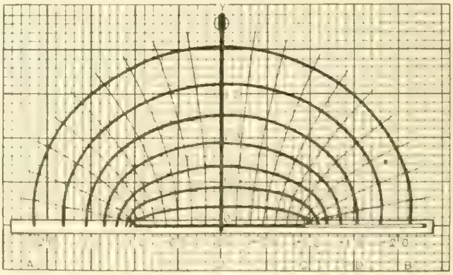


FIG. 47—PLAN VIEW OF MODEL

From a point on the *O Z* axis, 15 units from *O*.

followed between the axis $O\ C$ and the circular curve, will be $\frac{\theta_2}{2}\cosh^2\theta_1$ sq. dms.

From G, drop a vertical plummet, as in Fig. 46, on to the drawing board. In other words, project G orthogonally on the plane $X\ O\ Y$. Let g be the point on the drawing board at which the plummet from G touches the surface. Then it is easily seen that Og on the drawing board is the required magnitude and direction of cosh $(\theta_1 + j\theta_2)$, in decimeters, with reference to $O\ X$ as the initial line in the plane $X\ O\ Y$. It may be read off either in rectangular coordinates along axes $O\ X$ and $O\ Y$ on a tracing cloth surface as shown in Fig. 47, or in polar coordinates printed on a sheet seen through the tracing cloth.

If the circular angle θ_2, i. e., the imaginary hyperbolic angle $j\theta_2$, lies between π and 2π radians, (in quadrants 3 and 4), the point G will lie on the under side of the plane $X\ O\ Y$, and the projection onto g in that plane must be made upwards, instead of downwards.

If the hyperbolic angle whose cosine is required has a negative imaginary component, according to the expression cosh $(\theta_1 - j\theta_2)$, then starting from the projected point D, we must trace out the circular angle in the negative or clockwise direction, as viewed from the front of the model.

If the real part of the hyperbolic angle is negative, according to the expression cosh $(-\theta_1 \pm j\theta_2)$; then since cosh $-(\theta_1 \mp j\theta_2) = \cosh(\theta_1 \mp j\theta_2)$, we proceed as in the case of a positive real component, but with a change in the sign of the imaginary component.

The operation of tracing cosh $(\pm\theta_1 \pm j\theta_2)$ on the $X\ Y$ plane, thus calls for two successive orthogonal projections onto that plane; namely (1) the projection corresponding to cosh $(\pm\theta_1)$ as though $j\theta_2$ did not exist, and then (2), the projection corresponding to $\cosh j\theta_2 = \cos\theta_2$ independently of θ_1, except that the radius of the circle, and its plane, are both conditioned by the magnitude of θ_1.

If we trace the locus of cosh $(\theta_1 \pm j\theta_2)$, where θ_1 is held constant, it is evident from Fig. 47 that we shall remain on one circle, which projects into the same corresponding ellipse on the $X\ Y$ plane. That is, the locus of cosh $(\theta_1 \pm j\theta_2)$ with θ_1 held constant, is an ellipse, whose semi major and minor diameters are cosh θ_1 and sinh θ_1 respectively. If, on the other hand, we trace cosh $(\pm\theta_1 + j\theta_2)$ with θ_2 held constant, we shall run over a certain tie wire bridging all the circles in the model, which tie wire is sin θ_2 dm. above the board, and its projection on the board, in the plane $X\ Y$ of projection, is part of a hyperbola.

PROCEDURE FOR SINH $(\theta_1 + j\theta_2)$

It would be readily possible to produce a modification of this model here described, which would enable the sine of a complex angle to be projected on the $X\ Y$ plane following constructions already referred to. The transition to a new model for sines is, however, unnecessary. It suffices to use the cosine model here described in a slightly different way. One has only to recall that

$$\sinh\theta = -j\cosh\left(\theta + j\frac{\pi}{2}\right)$$

or

$$\sinh(\theta_1 + j\theta_2) = -j\cosh\left[\theta_1 + j\left(\theta_2 + \frac{\pi}{2}\right)\right]$$

Consequently, in order to find the sine of a complex hyperbolic angle, we proceed on the model as though we sought the cosine of the same angle, increased by $\frac{\pi}{2}$ radians or one quadrant, in the imaginary or circular component. We then operate with $-j$ on the plane vector so obtained; i. e., we rotate it through one quadrant in the $X\ Y$ plane and in the clockwise direction. An equivalent step is, however, to rotate the X and Y axes of reference in that plane through one quadrant in the reverse or positive direction. That is, we may omit the $-j$ operation, if, in dealing with sine projections, we treat $O\ Y$ as an $O\ X$ axis, and $-O\ X$ as an $O\ Y$ axis, or read off the projections on the $X\ Y$ plane to the $-Y\ O\ Y$ axis as initial line.

The only difference, therefore, between projecting the cosine and the sine of a complex hyperbolic angle in the model, is that in the latter case the circular component is increased by one quadrant and the projected plane vector is read off to the $O\ Y$ reference axis as initial line. The model thus gives the projection of either cosh $(\pm\theta_1 \pm j\theta_2)$ or sinh $(\pm\theta_1 \pm j\theta_2)$ within the limits of $+1.4$ and -1.4 for θ_1, and for θ_2 between the limits $+\propto$ and $-\propto$. For accurate numerical work, reference would, of course, be made to the charts and tables of such functions already published, and which enable such functions to be obtained either directly or by interpolation, for all ordinary values of θ_1 and θ_2.

Switching and Protection of Transmission Circuits-II

S. Q. HAYES

DISCONNECTING SWITCHES

To facilitate the inspection, adjustment or repair of an oil circuit breaker, it is customary to furnish disconnecting switches to isolate the oil circuit breaker from the busbars, incoming lines or other source of power. Suitable disconnecting switches have been designed and built for indoor and outdoor service at various voltages, and these are normally intended for operation as single pole units in the lower voltages, while for the higher voltages, particularly for outdoor service, it frequently becomes advisable to make them in the form of multipole units, mechanically operated.

A typical disconnecting switch is shown in Fig. 30, mounted on corrugated porcelain, pillar-type insulators that are attached to a steel base. Such a switch is normally intended for mounting with the base and blade in a vertical position, and the porcelain pillars in a horizontal position. The blade of this switch is built of truss form to secure rigidity and the break jaws are flared to facilitate proper alignment of the contacts during the closing of the switch. These switches are provided with a locking latch that prevents the switch being blown open by the magnetic stresses set up by short-circuits. The latch, however, is so designed that by inserting the end of the hook stick in the hole in the latch, and pulling on it, the latch is unlocked and the switch opened by the same operation.

Fig. 31 shows a disconnecting switch which can be arranged for upright mounting, vertical mounting or inverted mounting to best suit the wiring of the insulation. The pillar supports of this disconnecting switch are made up of a series of insulators bolted together. Each unit insulator consists of a porcelain bell provided with a cemented on cap and a cemented in hollow pin. These caps and pins are each provided with three lugs that fit together and are secured by half inch machine bolts. In this way, any section can be removed and replaced by another in a very simple manner. These insulators are suitable for indoor or outdoor service, and are the strongest and most rugged of this type manufactured.

A five unit insulator, such as shown, will withstand a dry arc-over test of 285 kilovolts, a wet arc-over test of 160 kv, and has a total height of a little more than 32 inches. The ultimate bending load of this column of insulators is 1760 pounds, the ultimate strength of the column in question is 18 000 pounds. Fig. 32 shows an inverted type of high-voltage disconnecting switch for the Windsor station of the West Penn Power Company.

Modifications of these high-voltage disconnecting switches can readily be arranged with three porcelain columns for each pole of the disconnecting switch. These columns are arranged in such a manner that the two outside ones carry stationary contacts, and the middle one carries a rotating arm arranged so that the combination will form a double break rotating type disconnecting switch. This type of switch can readily be arranged for mechanical operation from a distance and can be made three-pole if desired.

These disconnecting switches are intended only as isolating switches and are not expected to be used for opening the circuit under load. Where it is desired to have a high-voltage, air-break switch for outdoor service suitable for opening under load, it is necessary to provide arcing horns or similar devices to carry off the arc formed when opening under load.

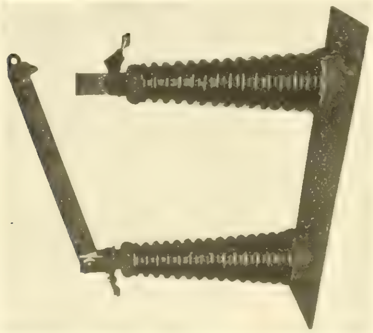


FIG. 30—600 AMPERE, 66 KV, PILLAR TYPE DISCONNECTING SWITCH

Fig. 33 shows a 36 kv horn gap switch made in single pole units but arranged so that any number of poles can be mechanically interconnected by means of an adjustable bar and operated from a single operating handle. As may be noted, the main contacts are protected from all burning by the auxiliary arcing horn which makes contact before the main contact is closed and which break away after the main contact is opened. The main contact itself is completely covered by a sleet hood. For 70 kv service these switches, as shown in Fig. 34, are made double break in order to obtain the proper gaps in the line. These switches are intended primarily for mounting on a pole top or a structure, with the insulators in the vertical position and the switch arm swinging around on a horizontal plane. For still higher voltages a switch of the type shown in Fig. 35 is utilized. This switch is designed for 120 kv service, and while the porcelain pillars are mounted in a vertical position, the switch arm is so arranged as to swing open in a vertical plane instead of in a horizontal one.

Where it is desired to obtain proper protection to a substation or sectionalizing of a line at a moderate cost, an automatic attachment can be added to the horn gap switches. The switch automatically resets by bringing the operating handle to the open position. The switch cannot be held closed on an overload. A modification of this trip mechanism can be applied to the double break or the vertical break horn type switch.

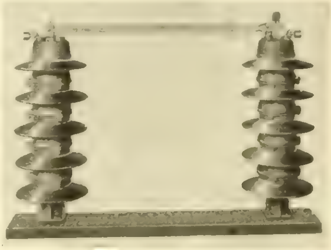


FIG. 31—DISCONNECTING SWITCH FOR 73 KV INDOOR SERVICE, 40 KV OUTDOOR SERVICE

RELAYS

The oil circuit breakers already described, as well as the automatic type of horn gap switches, are employed on power transmission systems and can be arranged for automatic or nonautomatic operation depending on the service. For automatic operation, various features in addition to straight overload tripping can readily be obtained by means of suitable relays, and the proper functioning of such relays is of vital importance in large systems for taking care of overload or short-circuit conditions on a certain section of the system without interfering with other sections, and the question of relay protection is therefore very intimately connected with all transmission problems.

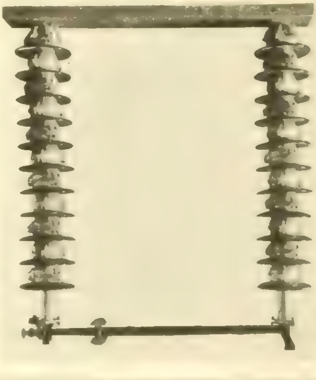


FIG. 32—INVERTED TYPE OF DISCONNECTING SWITCH FOR 132 KV SERVICE

The principal use of relays in connection with power transmission is to give to the automatic oil circuit breakers, other characteristics than those of plain overload, in order to facilitate the disconnecting of disabled sections of transmission lines and to handle properly the various operating problems arising on different systems. In applying relays, particular attention has to be given to the characteristics of the relays, circuit breakers, generators, transformers, transmission lines and other parts of the system.

It has been found, on various long distance transmissions, particularly those spread over a large territory, that a systematic study of the sectionalizing problem and a comparatively small expenditure for relays and slight rearrangement of switching apparatus will greatly improve the service to customers.

The number of short-circuits and grounds per year, occuring on any transmission system, varies greatly with the local conditions, but can be taken roughly as one ground or short-circuit per year for each 10 to 15 miles of line, so that approximately 100 cases of short-circuits or grounds per year may be expected on a system covering from 1000 to 1500 miles. By proper arrangement of relays on such a system, any trouble is localized and an extensive interruption due to line trouble can usually be avoided.

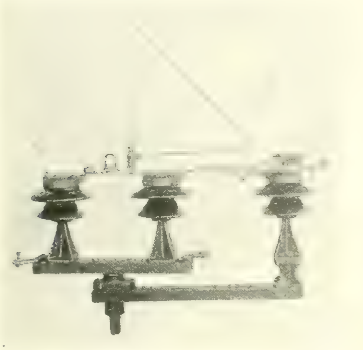


FIG. 33—36 KV HORN-GAP SWITCH

Relays can ordinarily be employed to the best advantage in connection with the distributing circuits, where important power consumers sometimes demand a separate set of feeders from the generating stations or main distributing transforming stations, in order that their service may not be disturbed by troubles on the remainder of the system. Such practice, however, requires an uneconomical amount of copper, because the load factor of the system cannot be utilized to its full advantage. A proper equipment of relays will allow the use of tie lines and inter-connections with the result that more load can be carried and the service to any particular customer will be improved, because more sources of power will be available.

The object of protective relays is essentially to obtain the utmost continuity of service, and this applies whether the relays are arranged to trip circuit breakers for disconnecting defective sections of line, or disconnecting apparatus which is causing trouble or has already become a source of disturbance. While there are different definitions of the term "interruption of service" a broad gage view of such a term would be any disturbance that would cause a loaded induction motor to stop. This will depend on the nature of the load and the characteristics of the motor but, in general, the voltage at the terminals of an induction motor can be reduced to zero for at least two seconds without interrupting it, and the relaying of the system will be considered satisfactory if it will clear cases of trouble in two seconds or less, thus avoiding the shutting down of induction motor load.

Relays are used to trip oil circuit breakers for automatically disconnecting any section of line and apparatus that is causing trouble, and for this purpose they usually give the greatest amount of satisfaction, although there are other methods of clearing disturbances without disconnecting the line, such as the use of arc suppressors, voltage killing devices etc.

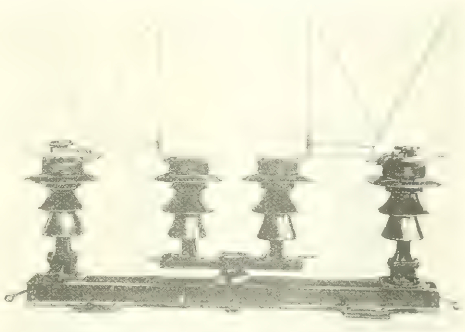


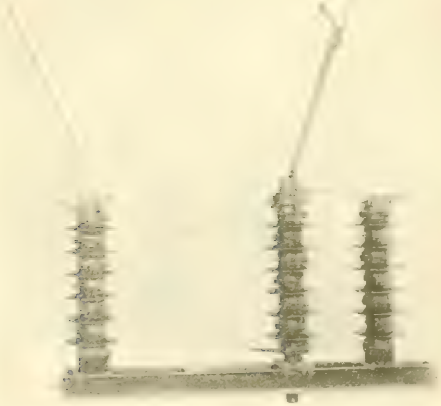
FIG. 3[illegible] [illegible] HORN-GAP SWITCH

Ordinarily a ground on an isolated neutral system will not cause an interruption, unless it should develop into a short-circuit, in which case a sectionalizing relay can operate to trip a circuit breaker for cutting off the defective portion of the line.

Circuit breaker characteristics must be considered in connection with the proper functioning of relays, a small circuit breaker operating usually more quickly than a large one. The time required to open a circuit depends upon its size and the inertia of moving parts. Circuit breakers of high rupturing capacity and moderate voltage, such as those used in the generator circuits and on the low tension side of transformer banks usually require from 0.2 to 0.3 of a second. Most of the time is consumed in energizing the trip coils and in overcoming the inertia of the moving parts. High-voltage circuit breakers, such as those considered in this article, require a slightly greater amount of time, ranging from about 0.3 of a second to almost one second for the 155 kv units with round tanks.

The proper relaying equipment for use on any transmission line will depend among other things on the [illegible] desirable or used. Where there is a single source of power with feeders radiating out from the generating station and possibly passing through one or more sectionalizing or transforming stations, proper selective action can usually be obtained by making the circuit breakers farthest from the power house practically instantaneous in their operation, those at the power house being provided with relays set for a definite time of from one to two seconds and the intermediate sections being provided with relays having various time settings.

In addition to securing discrimination on the part of the relays by means of a definite time feature, it is also possible to discriminate by the current setting, because trouble which occurs at the far end of a branch line will not draw as heavy a current as though it were closer to the source of power. Selective action can frequently be obtained to advantage by the use of an inverse time limit relay having characteristic curves similar to those shown in Fig. 36. This type of relay has an adjustable definite time element in addition to the inverse time, and the combination of these two is well adapted for the protection of circuits of this kind, because either the inverse time part of the curve or the definite time part can be utilized, depending upon the particular circuit standard.



[illegible] SWITCH

Such combination of definite time and inverse time is obtained in the relay shown in Fig. 37. The use of a permanent magnet as a time limiting device, prevents over-swinging and chattering of the contacts, and the construction is such that the relay will instantly cease its movement when the overload disappears.

One of the essential features of this relay is the torque compensator. This is essentially a small current transformer, having comparatively little iron in its magnetic circuit, so that it saturates at a little more than five amperes in the primary. With this device, the primary current can be increased momentarily to 200 times normal without increasing the secondary current more than a small percentage. As it is this secondary current that actually works on the relay mechanism, the force of the relay is practically constant, independent of the amount of the overload, so that its speed of operation is independent of the value of the short-circuit, and is determined by the restraining influence of the permanent magnet and the distance through which the contact has to move. As this distance is adjustable, the definite time setting on the standard relay can be made anything from 0.1 of a second up to 2 seconds, and in special cases up to 4 seconds. A current adjustment is also provided on this relay so as to secure normal operation with relay current varying from 4 to 12 amperes.

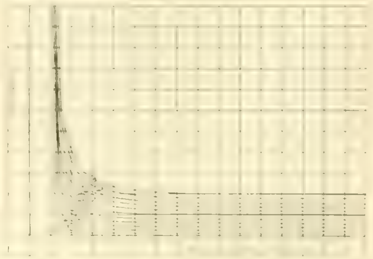


FIG. 36—TIME CURVES OF INVERSE TIME LIMIT RELAY

Where the distributing system, instead of being a radial one, is provided with parallel circuits between the generating stations and the points of distribution, such systems can sometimes be protected satisfactorily by means of inverse time element relays, if the short-circuit conditions are such that such relays can discriminate properly, but the more usual method of protecting service against trouble on parallel feeders is to place reverse power relays at the substation end of each feeder and definite time limit relays at the generator end.

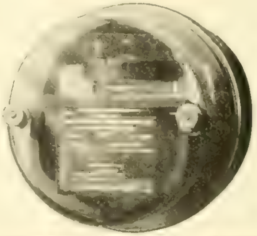


FIG. 37—[illegible] DEFINITE MINIMUM INVERSE-TIME-LIMIT [illegible] RELAY

A modification of the parallel feeder arrangement is the ring system where each substation is fed from two directions as indicated in Fig. 38. On such a system, definite time limit, reverse power relays must be utilized and the time limit of each successive relay should be increased by a sufficient amount to allow time for the circuit breaker in the preceding substation to open. On the diagram the time settings of the various relays have been marked, and for one-third second time interval will work satisfactorily if the relays are accurate and the circuit breakers quick acting. Such a system becomes somewhat more complicated if power is fed in at more than one point as, for example, if a generator ties in at station *D*. The adjustment of the relays in such a system would have to be modified, depending on whether the power was being generated at *A* or at *D*, so that it is evident that relays should have adjustments which can be changed quickly.

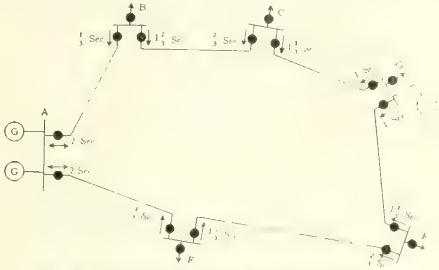


FIG. 38—DIAGRAM OF RING TRANSMISSION SYSTEM

For the protection of a parallel feeder system or a ring system, reverse power relays are necessary, and these can be made in the form shown in Fig. 39. This relay is essentially a two element relay. In addition to the current element there is a watt element that closes a contact whenever the flow of energy is in a reverse direction from the normal one. The current element closes its contacts on excess current in either direction, but the relay will not function to trip the circuit breaker unless the selective wattmeter element also functions due to the power being in the reverse direction.

While in many cases transmission and distribution systems can readily be sectionalized by the application of overload and reverse power relays, there are other conditions that can best be handled by a balanced system of relays. This system, utilizing pilot wire schemes and standard overload relays, operates from the secondaries of current transformers placed at two ends of the feeder, but such an arrangement requires conductors to be run between these current transformers and ordinarily on long distance transmission lines, such an arrangement is not very practicable.

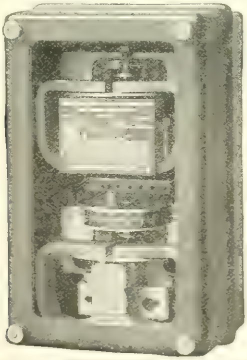


FIG. 39—ADJUSTABLE DEFINITE MINIMUM, INVERSE TIME LIMIT REVERSE POWER RELAY

A split conductor scheme can often be utilized to advantage where the power to be transmitted is such as to require two conductors in parallel. In most cases however, an arrangement of balancing relays on parallel feeders, using the cross connection of reverse power relays, will work out to the best advantage. Such an arrangement is indicated in Fig. 40, which shows four circuits between a generating station and a receiving station, omitting the step-up and step-down transformers normally used on high-voltage power transmission. This schematic diagram has been simplified by showing only one phase on each of the feeder circuits, the more complete diagrams applying, however, to a pair of three-phase circuits as shown in Fig. 41. By reference to these two figures it will be noted that the current transformers at the generating station are connected in series for each particular phase and similarly at the substation, and that each relay, which must be of the reverse power (uni-directional) type, is shunted across its own current transformers.

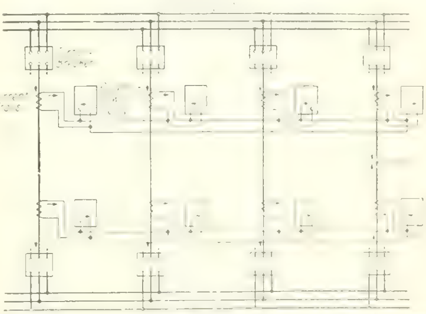


FIG. 40—SCHEMATIC [illegible]

The arrow shows the [illegible] on the right hand [illegible] shown and the voltage and trip circuits are omitted.

Under normal conditions the load in each of the parallel feeders will be the same, and since the relays have a higher impedance than the current transformers, the current from the latter will circulate through all of them in series without any flowing through the relays. If the trouble occurs at any point outside the section protected by the cross-connected relays, the current over the feeders will still be balanced and consequently there will be no force tending to operate the relays. In other words, a short-circuit occurring on some other portion of the system will have no tendency to trip out any of the circuit breakers in this section.

On the other hand, if trouble occurs at a point within the protected sections, the current over the defective circuit will be higher than that in the others, and this excess current from its current transformer must pass through the relays. While, under this unbalanced condition, current will flow through all of the relays, it will be observed that the current is in the proper direction to cause the relay to act only in the relays at each end of the defective section, as shown by the arrows in the diagram. In Figs. 41 and 42, pallet switches are connected in the transformer secondary circuit, and are mechanically operated by the circuit breaker so that, when the breaker opens, the current transformers are short-circuited. By this method, a feeder can be cut out of service without interfering with the electrical balance in the current transformer circuits.

Where there are only two parallel feeder circuits, a double-contact reverse-power relay connected as shown in Fig. 42 can be utilized. This relay is so arranged that, in case of trouble, the watt element will close the circuit leading to the trip coil of the circuit breaker in the defective circuit, and the excess current element will operate to trip out that circuit breaker under suitable conditions of overload and time element.

More complicated networks can usually be taken care of by proper selection of the type of relays to be employed. It frequently happens that the problem of automatic sectionalizing can be much simplified if, at the instant of short-circuit, a number of circuit breakers are opened for the purpose of simplifying the operation of the remainder of the systems. Fig. 43 shows such a complicated system, and on it is indicated a feeder between two substations, *N* and *S*, which normally assists in maintaining voltage regulation, but which can be dispensed with for a time if there is trouble on the line. As indicated on this diagram, it is assumed that the circuit breakers on section *A* at substation *N*, are equipped with an instantaneous relay. If it should happen that the trouble is on this section of the line, the relay in substation *S* will operate after one-half second and clear the trouble, but if the trouble is not on this particular feeder, no harm will be done and the load that is supplied will not be interrupted. If a short-circuit occurs, for instance, at the point *Z*, the relay in substation *N* will require one-fourth second to operate, if a minimum time limit of one-fourth second is provided, so that synchronizing and other switching on the system will not cause interruption.

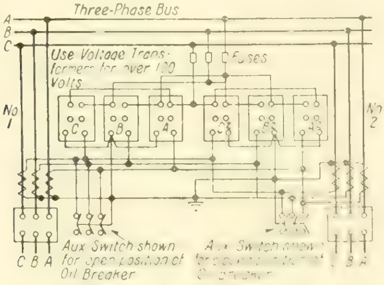

Three-Phase Bus
A
B
C
Use Voltage Transformers for over 120 Volts
Fuses
No 1
No 2
C
B
A
Aux Switch shown for open position of Oil Breaker
C B A

FIG. 41—DETAILS OF CROSS-CONNECTED [illegible] SYSTEM

Connections complete for a three-phase circuit, except for the trip circuits

After the relay has operated, one-fourth second may be required for the circuit breaker to open. The relays in substation *P* will not begin to operate until the circuit breaker at substation *N* has opened, on the assumption that the short-circuit is close to the latter substation and that there is consequently no unbalancing at substation *P*. There will, therefore, be a still further delay of one-half second at substation *P* before the trouble is finally cleared.

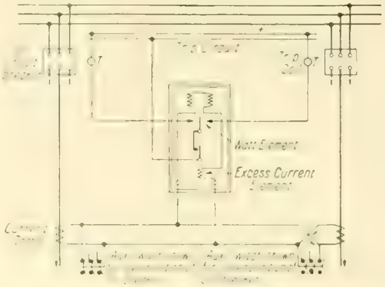


FIG. 42—DOUBLE-CONTACT REVERSE-POWER RELAY APPLIED TO DUPLICATE FEEDERS

Connections shown for one phase, voltage and trip circuits omitted

Various other features of relay operation, such as the effect of low voltage, effect of unbalance, short-circuits, etc., must be considered in proper relay application, but these cannot be taken up in a general article of this kind.*

LIGHTNING ARRESTERS

In addition to the oil circuit breakers with their disconnecting switches and relay equipment, the lightning arrester apparatus is one of the most important portions of the power transmission apparatus. While arresters of various types have been developed, and are in service, the electrolytic arrester has been found to furnish the maximum amount of protection and is the one most frequently employed where continuity of service and value of the equipment to be protected makes it advisable to furnish the highest grade of equipment.

The essential parts of an electrolytic lightning arrester are shown in Fig. 44. The arrester consists of a system of aluminum cup-shaped trays supported on porcelain insulators and secured in frames of treated wood, the whole arranged in a steel tank. The sys-

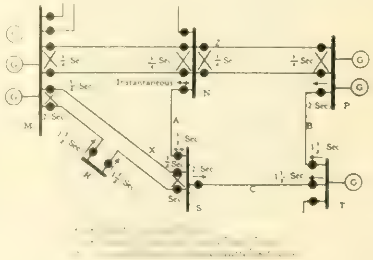


FIG. 43—NETWORK DISTRIBUTION SYSTEM

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*See article by L. N. Crichton, in THE ELECTRIC JOURNAL, Vol. XIII, p. 330

tem of trays is electrically connected between line and ground, and between line and line. These trays contain a liquid electrolyte which, on charging the arrester, forms a film on their surfaces. This film prevents flow of current at normal voltages, but forms a free path for abnormal voltages or static discharges. Upon cessation of the abnormal stress, the film regains its original resistance almost instantly, and prevents power current from following the discharge.

For high voltage service, horns with sphere gaps are used, and charge and discharge resistors are connected in series with the aluminum trays so that under normal conditions, no voltage is impressed on the trays.

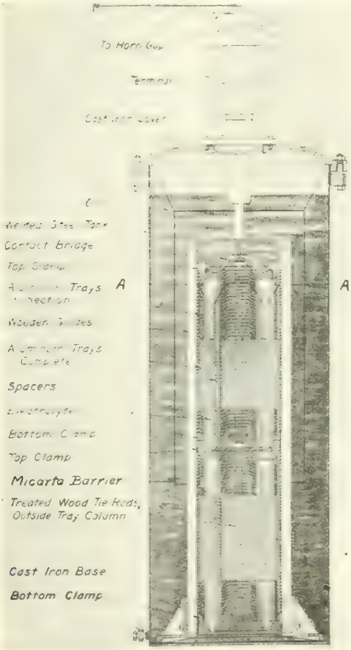


FIG. 44—SECTION THROUGH ELECTROLYTIC LIGHTNING ARRESTER

Abnormal voltage or high frequency surges will bridge the gaps, allowing current to pass into the trays. These aluminum trays are separated from each other by porcelain spacers arranged around the edge of the tray, insuring positive separation and ample space for the escape of such gases as are formed during a heavy discharge. The porcelain spacers vary slightly in thickness, but this does not affect the operation of the arrester because the resistance of the cell depends primarily on the film on the tray and only slightly on the electrolyte.

Fig. 45 shows the arrangement of tank bushings, trays and supports used for electrolytic arresters for 132 kv service. The tank is elliptical in shape with two terminals, the longer one connecting to the line circuit, the shorter one being used for the neutral connection. The tanks are grounded and the aluminum trays are mounted on insulated supports and provided with barriers to obviate the liklihood of any high voltage jumping from the trays through the oil to the grounded tanks.

The gaps used with these electrolytic lightning arresters have been made of the horn type, sphere type or impulse type. The horn type was first used and is still employed in many cases. It is so arranged that any arc forming will follow the natural tendency to rise and will be extinguished by the magnetic effect and the increased width of spacing at the top of the horn.

A sphere gap has a shorter dielectric spark lag than the horn gap, i.e. it has a greater speed of discharge. The use of sphere gaps on high-voltage arresters considerably increases the protection afforded the apparatus. On the lower voltage arresters, the rods forming the horn gaps are of such a diameter that they have practically the same effect as sphere gaps i.e., the gap is so small in proportion to the diameter of the horn that the effect is the same as if sphere gaps were used. Where sphere gaps are employed, they have a horn extension rising above the spheres to assist the arc to rise and thus be extinguished.

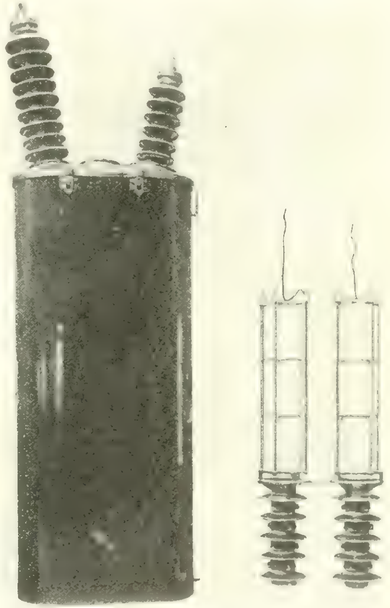


FIG. 45—132 KV ELECTROLYTIC LIGHTNING ARRESTER
Barriers not shown

The latest development along the line of high speed gaps is the impulse gap shown diagramatically in Fig. 46. The original horn gap has considerable time lag, allowing a high frequency surge to rise to a much higher voltage than a low frequency surge before discharging and giving protection. The sphere gap partly prevents this situation by eliminating the time lag, so that all frequencies are discharged at the same voltage. The impulse gap has a negative time lag, i.e. the higher the frequency, the lower the voltage at which the gap discharges. Thus the impulse gap automatically selects the dangerous surges and gives protection more quickly than any other known form of gap. With the impulse gap the high frequency discharge voltage may be as low as two-thirds or even one-third of the normal frequency value. It is therefore possible to use a gap setting that will premit the desired degree of protection against dangerous surges and will not permit too frequent discharging on minor surges at normal frequency.

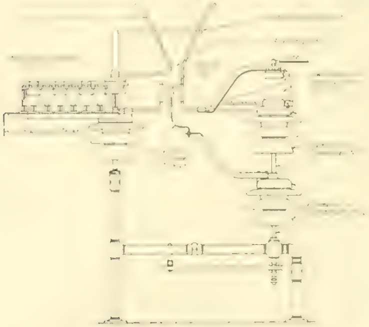


FIG. 16—IMPULSE GAP ARRANGEMENT

The high speed of the sphere gap as compared with the horn gap is due to the elimination of the time required to build up a sphere of equi-potential surface on the discharge part of the horn gap. The sphere gap provides at once for this, and practically eliminates corona. It does not however, give the desired protection against the steep-wave front or high frequency surges, due to its inability to discharge these disturbances at lower voltages than the normal frequency setting of the gaps. In the impulse gaps, however, the advantage of high normal frequency setting of the gaps can be had without the corresponding disadvantage of reduced protection, since the high frequency breakdown value of the impulse gaps is much lower. The impulse gap consists of porcelain insulators, two of which are used as condensers, an unbalancing resistor, auxiliary electrode or tickler, a sphere gap, an auxiliary horn gap, a short-circuiting clip, a charge and discharge resistor and a supporting frame-work.

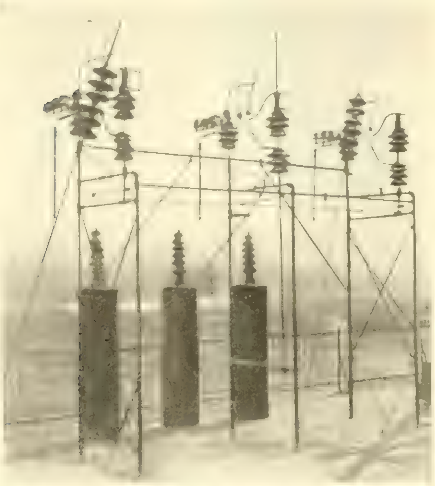


FIG. 17—INSTALLATION OF 66 KV ELECTROLYTIC ARRESTERS AND IMPULSE GAPS

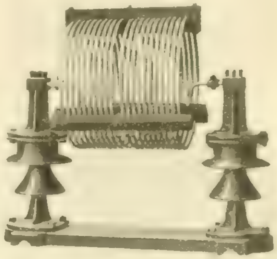


FIG. 18—50 KV CHOKE COIL FOR INDOOR OR OUTDOOR MOUNTING

The circuit of the impulse gap is balanced, with respect to voltage, at normal frequency, but becomes unbalanced and starts a discharge in case of high frequency surges. At normal frequency, there is no difference of potential between the mid-point of the condenser and the auxiliary electrode midway between the auxiliary horn and sphere gaps. A high frequency, however, passes freely through the condensers and piles up its full voltage across the resistance and carries across one half of the total gap. This gap, therefore, breaks down, resulting in the total voltage being impressed on the remaining gap which breaks down in turn. Breakdown at each half of the gap is facilitated by the fact that the auxiliary electrode is small in size, having needle gap characteristics, so that the discharge voltage at each half of the gap is about one-fourth rather than one-half of the total gap between the spheres.

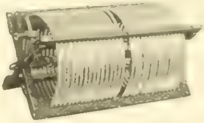


FIG. 19—LINE SUSPENSION CHOKE COIL

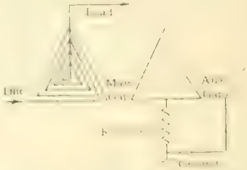


FIG. 20—DIAGRAM OF HORN GAP ARRESTER

It should be especially noted that the danger to apparatus from steep wave front surges, particularly of reverse potential, may be out of proportion to their actual magnitude, due to the inductance of apparatus which not only produces a high voltage across the first few turns of the winding of any apparatus, but also a much higher voltage to ground than the normal voltage of the impulse, due to the addition of induced or reflected voltage to the normal voltage of the impulse.

Fig. 47 shows an installation of impulse gap, electrolytic arresters used on a 66 kv, grounded neutral circuit, where only three sets of electrolytic cells are employed, one being connected from each outside circuit to ground, although the usual arrangement, whether for grounded or ungrounded circuits, contemplates the use of four sets of cells, three being connected in star between the outside wires and a neutral point, and the fourth being connected from this neutral point to ground.

Whenever a surge of high frequency or steep wave front, due to lightning or any other cause, travels along a line and strikes an inductive winding, it builds up a high-voltage between the end turns of that winding and also a high-voltage to ground. Choke coils are frequently furnished for use on line circuits to take the brunt of such surges, and to provide a point where the lightning arresters can be connected to secure the maximum protective effect. Besides relieving the end turns of the power apparatus from the first shock of the surges and flattening it out before it can enter the power apparatus, it delays the progress of the surge and piles up the voltage momentarily at the line end, thus giving the arrester more time and more tendency to discharge and relieve the line.

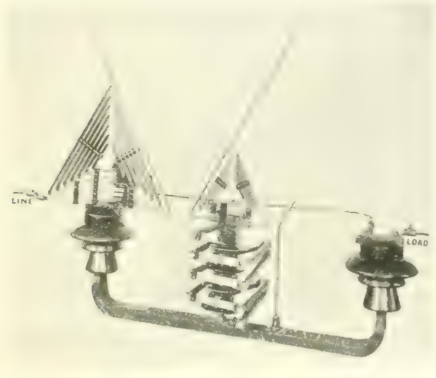


FIG. 51—HORN GAP LIGHTNING ARRESTER

With high capacity resistance, and with reactance coil in ground circuit.

While a very small choke coil has low protective power, very large coils will introduce excessive reactance in the line and impair the regulation. It is therefore necessary to choose a choke coil suited to the needs of the apparatus. Fig. 48 shows a choke coil suitable for 50 kv operation. The coil consists of 20 turns of aluminum rod formed into a helix 15 inch in diameter, and provided with bracing clamps to separate the turns rigidly and to give mechanical strength to the helix.

For outdoor service, the line suspension choke coil shown in Fig. 49 can be utilized to advantage. This coil can be inserted directly in the transmission line wire or station wiring and held in position by the tension of the line or station wires. Because no insulators are required solely to support this choke coil, and it can be installed in either a vertical or horizontal position, it can often be utilized very effectively in power and substation layouts.

For the plants of moderate capacity for outdoor high-voltage service, particularly where the lightning conditions are not very severe, the cost of electrolytic lightning arresters may not be justified by the value of the equipment which they are protecting. For such cases, horn type lightning arresters can be utilized to advantage. Such arresters are usually combined with triangular shape choke coils as shown in Fig. 50. With this arrangement, one side of the choke coil acts as one of the horns of the arrester. The coil is used in this way first as a magnetic blowout to hasten the travel of the arc up the horns, and second to increase the speed of operation of the arrester. The incoming line is connected to the outside turn, and the path of the power circuit is around the coil and out through the center, so that the surge entering the coil meets its first obstruction at the first sharp upward turn of the coil opposite which is mounted the ground horn. The voltage will build up at this point and is reflected back by the other turn toward ground. Due to this construction the gaps to ground may be set approximately 50 percent greater than the ordinary shunted horn gaps with the same protection obtained.

A surge acts as though it had momentum, and continues to travel straight ahead, if possible. A sudden change in direction, results in piling up voltage at the turning point. A surge will arc to ground where the resistance to ground is weakest, or where it meets an obstruction. In the arrester illustrated, a most efficient obstruction to surges and a point of weak resistance to ground are concentrated at the same point, and back of this point the load is connected to the line.

Fig. 50 shows a diagram of this type of arrester using a choke coil, main and auxiliary gaps and resistance. A resistor is permanently connected in the ground circuits of each phase, but an auxiliary horn gap shunts this resistor, affording a direct path to ground for heavy surges or a direct stroke of lightning. The use of resistance permanently connected in the ground circuit does not affect the sensitiveness of the arrester.

For more severe lightning conditions, the type of horn arrester shown in Fig. 51 is used. This arrester is similar to the one previously described, except that a reactance coil is connected in series with the high capacity resistance in the ground circuit. An auxiliary horn gap shunts both the reactance coil and the resistance, thus giving a direct path to ground to a surge of such capacity that it cannot be discharged quickly enough through the reactance and resistance. This reactance is used principally to relieve the resistance of the heavy strain, by smoothing out the surge before it reaches the resistance. The use of the reactance coil in no way interferes with sensitiveness of the arrester.

THE
ELECTRIC
JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

JUNE
1920

Field Winding Diagrams for Railway Motors—I

Before attempting repairs on the field windings, it is important that the operator should understand the relations between the various types and combinations of field windings that are in common use. The most important of these are:—

1—Non-commutating pole motor—With four main field coils, each coil having two leads, as shown in Fig. 1.

2—Commutating pole motor—With four main field coils, each coil having two leads, and four commutating field coils, each coil having two leads, as shown in Fig. 2.

3—Commutating pole motor—With four main field coils, each coil having two leads and three commutating field coils, each coil having two leads.

4—Commutating pole motor—With four main field coils, each coil having two leads and two commutating field coils, each coil having two leads, as shown in Fig. 4.

5—Commutating pole field control motor—With four main field coils, each coil consisting of two separate coils (short and added coil) assembled together, with each assembled coil having four leads, and with four commutating field coils, each coil having two leads, as shown in Fig. 5.

In general, any of the above combinations can be used both on the split frame and box frame types of motors, and with the leads on either the axle or the suspension side.

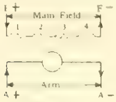


Fig. 1

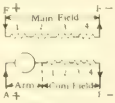


Fig. 2

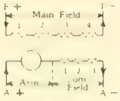


Fig. 3

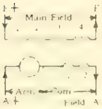


Fig. 4

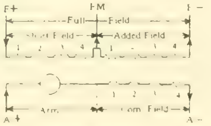


Fig. 5

The marking of the motor cable leads outside the frame is shown on tags attached to the cables, and these markings should agree with those given on the winding diagrams as furnished by the motor manufacturers.

During the general overhauling period, when the field coils are taken out of the frame to be cleaned, redipped in insulating paint or varnish and baked, or when damaged coils are being replaced, it is very important to get them put back in the frame properly, with the leads so connected as to give the correct relative polarity, to secure the required magnetic flux. If for any reason one or more of the main field coils should be connected so that current passes through them in the wrong direction, this motor would run at a higher speed, and when put on the car would tend to "hog" the load and result in overheating the armature. Should one or more of the commutating pole coils be connected in wrong, the motor would commutate poorly and tend to flash-over from the brushholder to brushholder or from brushholder to ground.

In order to prevent wrong connections, when frames are being overhauled or repaired, and to aid the operating man in connecting the field coils to give satisfactory operation, a standard winding diagram of a modern commutating-pole motor with four commutating field coils (Fig. 2) is shown in Fig. 6.

PRECAUTIONS IN REPLACING FIELD COILS

The following points are well worth following while overhauling or repairing field windings.

1—Coils and frame should be cleaned and painted.

2—Coils should be placed on poles properly.

3—Coils should be spring supported, and where necessary, backed up by washers of either metal or fibrous material, well painted.

4—In replacing coils temporarily, tape the spring and washers to the coil to keep them from working out of place and getting in between the pole and pole seat when assembled.

5—Clean the surface of the pole and pole seats, to insure a good close fit when the bolts are drawn up tightly.

6—Do not pound the pole in place with a sledge—use a block of wood or a piece of soft metal, such as copper.

7—Be sure that the pole bolts are drawn up tightly and that lock washers are under each nut. Add some white lead over the nuts after tightening to prevent entrance of water.

8—Sound the assembled pole, using a small hammer, to insure that the poles are drawn up tightly.

9—Connections should be made as shown on the winding diagram.

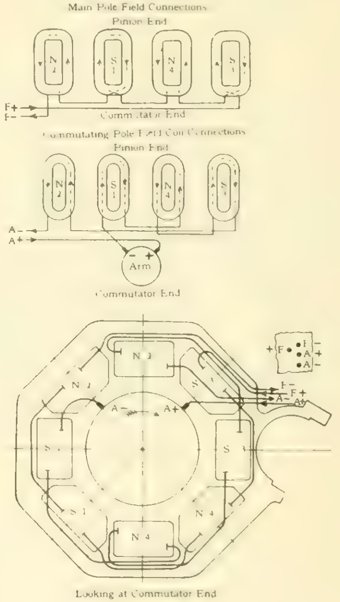


FIG. 6

10—Check the polarity of each coil. (See Railway Operating Data for December 1916.)

11—The connections between coils with cable leads should be made by butting the ends together, covering the joint by a copper sleeve and soldering well.

12—When the coils have terminals, the ends of the cable connected to the terminal should have a metal sleeve soldered to the wire, which is held in the terminal by screws securely tightened and locked.

13—The ends of the cables connected to the brushholders should be provided with metal sleeves or terminals that are to be securely clamped and locked to the brushholder casting.

14—All wiring-around-frame should be securely anchored to the frame and tied down, to prevent vibration and to keep the insulation from being rubbed or cut by parts of the rotating armature.

15—Dip and bake the individual coils. To secure best results, dip and bake the entire frame after the coils are in place and all connections are made.

16—The motor leads where they come out of the frame should be well protected by insulating bushings.

John S. Dean.

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

To receive prompt attention a self-addressed, stamped envelope should accompany each query. All data necessary for a complete understanding of the problem should be furnished. A personal reply is mailed to each questioner as soon as the necessary information is available; however, as each queston is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply.

1877—CHANGING THE SPEED OF MOTOR DRIVEN PUMPS—I have a 50 hp, three - phase, six-pole, 550 volt, squirrel-cage motor direct connected a six-inch, single-stage Watson-Stillman pump, which at its present speed maintains 50 pounds water pressure. I wish to increase the water pressure to about 75 pounds using the same quantity of water, which is about half the pump capacity. I propose changing the motor to a two speed motor by two sets of coil connections, one six pole and the other four pole to get about 1800 r.p.m., at which speed the pump is safe to operate. Will this increase in speed give the desired pressure? Also advise if the motor will stand the increased speed, if the scheme is feasible, and show by sketch the coil connections for the proposed change. Give the horsepower rating and efficiency as a four-pole motor. E.W.B. (ONT.)

The pressure at constant flow at four-pole speed will be approximately two and one-half times that at six-pole speed; therefore, the horse-power at four-pole speed would be approximately two and one-half times the horsepower at six-pole speed. The head or pressure is approximately proportional to the square of the speed, the volume being proportional to the speed. As the volume in your case is to remain constant it is necessary to make allowance for the increase in head due to throttling of the discharge. With constant speed the volume will vary approximately inversely as the square of the head. It would be impossible to put the two windings in the slots for four and six-pole operation. As stated, the motor is now carrying about 50 percent load, but if run at four-pole speed the load would be two and one-half times the present load or a 25 percent overload. This would mean a six-pole winding, good for approximately 25 hp, and a four-pole winding good for 65 hp, in the same space as now occupied by the 50 hp, winding, which would be impossible. T.W. & C.W.K.

1878—DEMAGNETIZING TOOLS—I have much trouble with tools and sometimes my watch getting magnetized. Please tell me how to make a coil that will neutralize the magnetism using 110 volt, 60 cycle, alternating current. J.B.W. (VA.)

To make a coil about three inches inside diameter and three inches long, wind 300 turns of No. 18 wire and place it in series with a 40 watt lamp across 110 volts alternating current. This gives a magnetizing force of about 36 ampere-turns per inch. If a coil is desired which is to be placed directly across 110 volts, about 200 turns of number 32 wire would be necessary. In demagnetizing objects, leave them inside of coil for only a few seconds and then withdraw them very very slowly. D.F.M.

1879—WELDING AND BURNING OUTFIT—I would like to know if a bank or several banks of grid resistance could be connected in series with a carbon electrode and connected on a 240 volt direct-current power circuit in order to get 500 amperes at the arc. Or is this voltage too high for practical work. A.W.P. (IND.)

Allowing 40 volts arc drop, it will require 0.4 ohms resistance, or 10 frames of 8 inch, three point, cast-iron grids properly connected in series with the arc to obtain 500 amperes from a 240 volt direct-current line. We have several similar installations and have found three reasons which make this arrangement undesirable; namely:—loss of power in the resistance, which in this particular case is approximately 80 percent; danger to the operator, since it is very easy for him to get across full line voltage; and poor welds caused by holding a long arc, made possible with high voltages. The last objection is entirely under the control of the operator, since he can hold either a short or a long arc. Taps on the resistor for securing different current values will greatly increase the flexibility of the unit and make it applicable to various grades of welding. See article on "Arc Welding of Mild Steel" by O. H. Escholz, in the JOURNAL for July, 1918, p. 247. H.E.D.

1880—SPACING OF WOOD POLES—What is standard practice in the spacing (distance between poles) of wood poles for power transmission, using No. 8 hard drawn copper wire. Voltages 6600 and 13 200. F.L.S. (CUBA)

According to the Bureau of Standards, National Electrical Safety Code, paragraph 221-b, "No wire smaller than No. 6 if soft copper, No. 8 if hard or medium copper, nor less than No. 9 (Stl. W.G.) if steel, shall be used for supply lines in urban districts. It is recommended that these minimum sizes shall not be used in spans longer than 150 feet in heavy loading districts and 175 ft. in medium and light loading districts." We believe that 200 foot spans could be safely used in Cuba, which we understand never experiences sleet storms. Table I, giving data from actual installations, is taken from the insert on page 212 of N.E.L.A. Convention Reports of May, 1916.

TABLE I—LENGTH OF SPAN

Location	Length Miles	Voltage	Poles	Span Feet	Primary Conductor
Eastern Washington.	31.39	6900	8 in.—35 ft.	150	No. [illegible] aluminum
			7 in.—40 ft.	125	No. [illegible] copper
Eastern Washington.	19.65	6900	[illegible]	200	No. 4 iron
			7 in.—40 ft.	125	[illegible]—No. [illegible] copper
Eastern Washington.	25.45	6900	[illegible]	150	3—No. 3 aluminum
			7 in.—40 ft.	12[illegible]	[illegible]
Central Washington.	7.2	[illegible]	35 ft.	250	3—No. 6, No. 8 and No. [illegible]
Central Washington.	1.8	6600	[illegible]	140	2—No. 8, No. 6 and No. [illegible]
Central Washington.	1.08	6600	35 ft.	[illegible]	[illegible]
Central Washington.	0.52	2300	[illegible]	195	[illegible]
Central Washington.	0.52	6600	35 ft.	[illegible]	[illegible]

O.M.J.

1881—METERING LOW POWER FACTOR, THREE-PHASE LOAD—Please state the relative merits of the following three methods of metering three-phase energy, particularly in the case of loads of extremely low power-factor, as encountered in the metering of synchronous condenser losses: (a)-A two-element poly-phase watt-meter. (2)—Two single-phase watt-hour meters. (3)—Three single-phase watt-hour meters, with the potential coils connected star. H.M.J. (MASS.)

A two-element watt-hour meter is preferable, because it automatically records the algebraic sum of the amounts of energy measured by each of the watt-hour meter elements. The two meter method is not as satisfactory as the poly-phase meter method, because one of the meters rotates in a negative direction when the power-factor of the circuit is less than 50 percent, thus making it necessary to take the algebraic sum of the meter readings to determine the total energy in the three-phase circuit. Three watt-hour meters with the potential coils connected star will each rotate in a positive direction regardless of the power-factor of the circuit and the total energy is the sum of all the readings. However, the artificial neutral obtained by the star connection of the voltage coils is sensitive to line disturbances and the effect of higher harmonics. Inasmuch as the two element polyphase meter consists simply of two single elements mounted on the same shaft and having the same power-factor adjustment for low power-factor, there should be no difference between the accuracy of the three methods from this standpoint. H.F.

1882—DIFFERENCE BETWEEN KW AND KV-A—Will you please explain the difference between the expression kw and kv-a in their relation to alternating-current machinery? For example, in the formula $kw = \frac{E \times I \times \text{power factor}}{1000}$ which is used to compute the kw output of an alternating-current, single-phase generator, could kv-a be properly substituted for kw? G.D.C. (N.Y.)

Kw refers to the power actually represented in a circuit. Kv-a represents the product of the volts and amperes divided by 1000; in a three-phase circuit it equals the product of the sum of the three currents multiplied by the average voltage between phases and divided by 1000 times the square root of three. The ratio between the kw and kv-a equals the power-factor; in fact this is the definition of power-factor. Hence the terms kw and kv-a cannot be used interchangeably except at unity power-factor. The term kw is used whenever the actual power that is passing through electrical apparatus is referred to; hence it is used in connection with meter readings and in expressing power consumption. The term kv-a is ordinarily used when the temperature rating of apparatus is in question. For instance, transformers are usually rated in kv-a, as the limit of transformer capacity is determined by the product of voltage and amperes, and not by the actual power which passes through it. In a similar way, the output of a generator is usually spoken of in kv-a, as the product of voltage and amperes again ordinarily determines the maximum carrying capacity rather than the actual power output. When dealing with transformers or similar apparatus a rating of 6000 kw at 100 percent power-factor; a rating of 6000 kv-a; and a rating of 4800 kw at 80 percent power-factor amounts to the same thing —in other words, these three ratings are identical. In a generator however, these three ratings would not specify identical machines, as a machine must have more field excitation to supply 4800 kw at 80 percent power-factor than to supply 6000 kw at 100 percent power-factor. Hence a generator rated at 4800 kw at 80 percent power-factor would be a larger machine than one rated at 6000 kw at 100 percent power-factor, although the kv-a rating would be the same in both cases. C.R.R.

1883—Generator Fuses — Is it the present practice to fuse an alternating-current generator either at the switchboard or at the generator. Size of the generator in this case, 225 kv-a., three-phase, 60 cycle, 240 volts. A.H.A. (ILL.)

It is not the practice to provide automatic overload protection for alternating-current generators. Automatic overload protection should be provided for feeders either in the form of fuses or circuit breakers. Where a single alternating-current generator feeds to a single feeder circuit, automatic overload protection should, of course, be provided in that circuit. J.M.B.

1884—Inverted Current Transformer —Would it always be accurate under all conditions to use an ordinary series current transformer inverted? That is, with a transformer with a five ampere, secondary, ratio 20:1, would I get 100 amperes, in the primary in all cases? R.A.S.

A series transformer is usually not very accurate when used inverted. This is because the ratio of transformation is not the same as the ratio of number of turns, because current transformers are compensated for the impedance drop in their windings, by having the ratio of turns somewhat less than the rated ratio of transformation. Thus a transformer which has five amperes secondary current with 100 amperes in the primary would not give 100 amperes in the secondary when run inverted with five amperes in the primary, but the secondary current would be less by twice the amount of the compensation, which might amount to several percent. C.R.R.

1885—Generator Wiring—The distance from a 225 kv-a, three-phase, 60 cycle, 240 volt generator to the switchboard is about 60 ft. It is proposed to run wires in an open space left in the cement floor a distance of 18 feet to the wall, then run open on the face of the wall to the board. Would it be best to use three lead covered cables or rubber covered wire in conduit, where the wires run in the floor? Would a 600 000 circ. mil. cable be large enough? The load is nearly all in motors. A.H.A. (ILL.)

225 kv-a, three-phase at 240 volts means a current of about 550 amperes. On the basis of the underwriter's rules, this current would require 800 000 circ. mil. cable if rubber insulation were used, or about a 500 000 circ. mil. cable with slow burning insulation. Single conductor lead covered cable of 500 000 circ. mil. section could also be used for this current. Assuming that the conduit and cables will not be exposed to moisture, we would recommend that cable with slow burning insulation of 500 000 to 600 000 circ. mil. cross section be applied both in the conduit and for the open wiring. This will give the most economical arrangement and at the same time should be entirely satisfactory. In case there is danger of moisture being present, we would recommend single - conductor, lead covered cable of the same cross section recommended above. The lead covered cable will, of course, be more expensive than the cable with slow burning insulation, and unless moisture is present it would hardly be justified in this case. R.C.S.

1886 Alternator Insulation — Upon examining the rotor of one of our 1000 kv-a, turbo-alternators we found the horn fibre insulation between the rotor coils and slot wedges badly charred, the insulation in the slots nearest the pole being the most affected. Do you think this was caused by the machine being run single-phase (we have no knowledge of this occurring) or due to an excessive field current? The machine is 60 cycle, 2300 volt, 3600 r.p.m., star connected, and has been in service about two years W.N.W. (OKLA.)

The rotor of the generator may be running hot, due to the machine carrying badly unbalanced load or to excessive field current required, due to the machine operating at a lower power-factor than it was designed for. If the maximum difference in line current between phases does not exceed ten percent of the rated current, the heating is probably not due to unbalanced load, but rather to excessive field current. The temperature of the field should be measured by the resistance method and if the field is insulated with fishpaper and fibre, as it seems to be, the total temperature should not exceed 105 degrees C.; or, if the field is insulated with mica, the total temperature should not exceed 150 degrees C. The cold resistance should be measured after the machine has been shut down at least thirty-six hours and checked with a value obtained from the manufacturer, to determine whether there are any short-circuits which might cause local heating. The temperature, by the resistance method, can be found as follows: —The resistance should be measured with a direct-current voltmeter and ammeter, which have been previously calibrated, and the voltages should be read across the collector rings, and not across the brushes. With the machine under the maximum load which it carries, and after it has been carrying this load for three or four hours, measure the hot resistance. The total temperature of the field will be given by the formula–

$$\text{Total} = \frac{R_t}{R_{25}} \times 259.5 - 234.5$$

where R_t = hot resistance at any cooling air temperature, and R_{25} = cold resistance at 25 degrees C. cooling air temperature. If the cold resistance is measured at some other temperature, than 25 degrees C. it can be corrected to 25 degrees C. as follows:

$$R_{25} = R_x \frac{(1 + 0.00427t_{25})}{(1 + 0.00427t_x)}$$

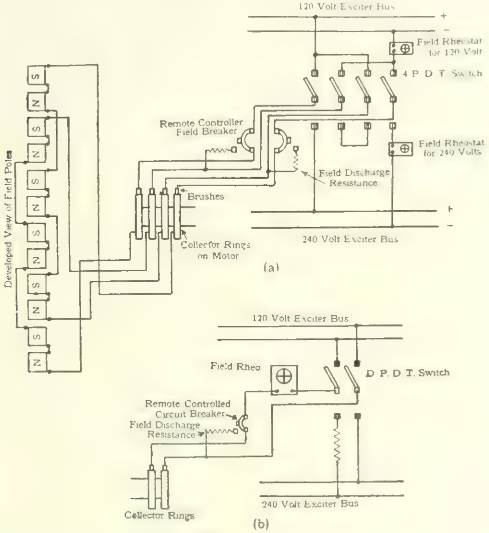
If the machine exceeds the limits given above, and there is only slight unbalance, the characteristics as to power-factor and kv-a rating should be checked with the manufacturer. S.L.H.

1887—Special Field On Sychronous Motor—We are planning to install a synchronous motor generator set to carry part of our direct-current load, and also to use as a condenser on the alternating-current system. The synchronous motor will be of extra capacity, so it will be able to pull the direct-current load and at the same time have sufficient capacity to raise the power-factor of the station, considerably.

Our plant has two exciting systems, of 120 volts and 240 volts respectively. All our alternating-current generators operate in parallel, but some are wound for 120 volt excitation and others for 240 volt excitation. Each exciter system has its own separate Tirrill regulator. As both of these exciter systems are not always in operation it would simplify matters if we could obtain a synchronous motor that could be excited from either bus. Would it be practicable to have a special field winding on the motor so it could be operated from either 120 or 240 volts? That is —two field circuits, each for 120 volts brought out to four collector rings and connected to a four-pole, double-throw switch on the switchboard, which would connect the two field circuits in parallel for 120 volts and in series for 240 volts? Fig. (a) will make my idea more clear. Our present synchronous motors are excited direct from the 90 volt generators which they drive, and are independent of the exciter busses. When operated as condensers they seem to have a decreasing effect on the power-factor, as the alternating-current load increases. The writer has it in mind that if a synchronous motor on the system were excited from the station exciter bus, the voltage regulator would automatically keep the power-factor up, as the load increased, by in-

creasing the exciter voltage and therefore the field current in the synchronous motor. Would such a synchronous motor be operative and would the effect be as outlined above?
J.C.E. (OHIO)

The idea embodied in the question is feasible, but such innovations involving complications in standard construction are objectionable on account of the added expense of manufacture, when there are other means of surmounting the difficulty. We would suggest as another possibility a scheme such as is shown in Fig. (b). The complications are considerably reduced, while the extra losses are incurred by the constant resistance *R* only when it is impossible to excite from the 120 volt bus, which would be considered normal operation. Only one field rheostat will be required for this arrangement and the only extra apparatus for 240 volt excitation will be the double-pole, double-throw switch and the ballast resistance. E.B.S.


120 Volt Exciter Bus
+
−
Field Rheostat for 120 Volt
4 P D T Switch
Remote Controller Field Breaker
Field Rheostat for 240 Volts
Developed View of Field Poles
S
N
Field Discharge Resistance
Brushes
Collector Rings on Motor
240 Volt Exciter Bus
(a)
120 Volt Exciter Bus
Field Rheo
D. P. D. T. Switch
Remote Controlled Circuit Breaker
Field Discharge Resistance
Collector Rings
240 Volt Exciter Bus
(b)

FIGS. 1887 (a) and (b)

1888—TRANSFORMER OPERATION —We have a bank of three single-phase transformers, connected delta on both sides, 300 k.v.a, 13 200/575 volts,25 cycles. Recently I have noticed an unusual noise like the chirping of a cricket coming from the bank and usually at about the same time each evening, which lasts only a few minutes. I have been told that this is caused by arresters being charged somewhere on the system. Is this correct, and how is it accounted for?
C.P. (ONT.)

The changing of arresters often sets up disturbances on the connected lines. These disturbances are at comparatively high frequency, and although they are small in magnitude and harmless to connected apparatus, they are often audible when passing through inductive machines, such as transformers. It is probably that the noise in this case is due to charging arresters. J.F.P.

1889—CEMENTING .LAMP .BULBS. —We have several stereopticon and other heavy current Mazda lamp bulbs, in which the glass bulb has become loosened from the brass base. The lamps are otherwise in good condition, but we are afraid to use them for fear of twisting the leads together. Can you tell us how to recement the brass base to the bulb?
D.C.H.R. (PA.)

We do not know of any way to remove the cement which has loosened in the bases of these bulbs. It is possible that the bulbs could be reclaimed by immersing the base of the bulb in water glass and allowing it to soak until the water glass has had a chance to penetrate the crevices of the defective cement. This will be perhaps one-half hour. Then lift the bulb out of the water glass and carefully wipe off the material from the brass base so that the electrical contact will not be impaired. Then allow the water glass to set for about 48 hours, at room temperature. L.E.F.

1890—UNBALANCED LOAD—In a three-phase, 625 kw, 480 volt, alternating-current generator, what percent of full load current, unbalancing between phases, can there be without injury to the generator?
S.J.P. (MICH.)

The question of the amount of unbalancing which a given generator will carry without damage depends considerably on the design of the particular unit. Unbalance of the currents causes additional heating in the field, due to double frequency current, in the same way as a single-phase load, which is really a special case of unbalancing. The amount of this double- frequency current which can be taken care of on the field, without causing serious heating, depends on whether or not the field has a damper winding and also upon the relation between ampere-turns in the armature and the total flux. That is to say, a high flux and a low ampere-conductor machine would take care of a larger percentage unbalance than a machine of the reverse characteristics. The average machine without a damper winding will take care of a difference in current between maximum and minimum phase of approximately ten percent of the rated current, and if the machine has a damper winding, the maximum difference can be 100 percent or, in other words, a single-phase load. In any event, the heating on the field is the limiting feature, and if the load is unbalanced, the temperature of the field should be checked by the increase in resistance method. S.L.H.

1891—STARTING INDUCTION MOTOR—How is the primary current of a slip-ring motor affected by inserting resistance in the rotor circuit? A.R. (OHIO)

The primary current varies with the torque which is produced by the motor and the only effect the secondary resistance has, is to change the speed at which the value of torque is delivered. The primary current is a function of the torque and is not directly dependent on the secondary resistance. C.W.K.

1892—MAGNETIC DETECTOR FOR IRON—A conveyor belt 18 inches wide by 10 ft. long delivers rags and old clothing to a rag cutting machine which cuts it up into small pieces to be used in the manufacture of paper. Now, it frequently happens that small pieces of iron and steel, accidentally mixed in with the rags, are carried into the cutting machine, where they do considerably damage to the cutting knives. It has occurred to me that some kind of detecting coil placed immediately under the conveyor belt and used in conjunction with relays and signal bells, could be made to indicate the presence of these objectionable articles of iron and steel coming within say a 12 inch zone of its influence. The attendant, on receiving the signal, would at once remove that portion of the rags containing the iron article. Could I expect results should I experiment to attain the object as outlined above? Could you give me a hint as to what line to follow to attain this object? I am aware of a system of coils for locating iron ore. (See Hopkins "Experimental Science" 23rd edition, Vol. II, page 330). F.T.S. (CALIF.)

It is possible to make an indicator which will show magnetic particles passing along the conveyor belt. The indications will be rather feeble unless the particles have large dimensions or pass close to the detecting coil. In order to make a reliable device, considerable complication may have to be resorted to, such as the use of amplifiers or photo-electric cells. We would suggest that an alternating-current bridge be constructed, fed preferably by 25 cycles. Two adjacent arms should have non-inductive resistance and the other two adjacent arms air coils—one of these coils being the detector coil co-operating with the belt. The galvanometer diagonal of the bridge should contain a tuned galvanometer of the Campbell type, arranged to operate a relay by means of reflected or interrupted light. When non-inductive material is in the detector coil an ohmic and inductive balance is made, so that the galvanometer shows no deflection. When magnetic material passes near or through the detector coil the inductance of this coil is increased and destroys the balance of the bridge. If the rags are rather deep as they pass along the belt, it would be wise to put a detector coil under the belt with the axis vertical and having dimensions inside of the coil of 18 by 4 by 4 in. In order to bring the rags and magnetic particles near to the coil, a non-magnetic roller could be placed just above the coil so as to press the rags down at this point. If the rags are not deep, tests should be tried by passing the belt through a coil having its axis parallel to the direction of travel. If the rags passing along the belt are of small size and very loosely and thinly piled, it seems as though a strong magnet placed above the rags should pick up magnetic particles and possibly rags. When these stick to the magnet, a sensitive mechanical electrical contact could be operated by the drag of the passing belt and ring a bell. The practical solution of the detector asked for, can best be determined by experimental trial. Such apparatus is easily worked in a laboratory, but is more difficult to use in such a factory. L.W.C.

1893—Calculating Resistor for Induction Motor—When building a starting resistance for a slip-ring type induction motor, how is the ohmic value computed? Please explain this fully. G.W.S. (CAL.)

It is first necessary to obtain the secondary volts and amperes of the motor, that is, the voltage between rings with the rotor locked and the full load current in the secondary windings. The required resistance per phase can then be calculated by assuming the percent of full-load current desired and dividing the voltage per phase by the current per phase. Three-phase balanced resistors are commonly used, and for a star connection the voltage per phase is the voltage between rings divided by 1.73, while for a delta connection the current per phase is the current in the windings divided by 1.73. The division of the resistance per phase into steps and their capacity is determined the same as for a direct-current motor, and the total resistance consists of three identical phases. See article on "The Design of Direct-Current Accelerating Resistors" by L. J. Hibbard in the Journal for October 1916. H.C.N.

1894—Design of Generator Shafts—Please discuss the limitations of the size of a generator shaft due to the combination of shearing and bending stresses; also the different considerations in the design of a turbine and reciprocating engine driven generator shaft. P.S. (N.Y.)

The vertical shear is usually neglected in calculating generator shafts. Usually, the only shear stress to consider is that due to torsion. The bending stresses are important as each fiber in the shaft is alternately in compression and tension for each turn of the shaft. This stress may be quite high for low speeds, but must be lower with higher speeds. Shaft deflection is also important. These points are clearly explained in "Mechanical Design and Construction of Generators" by Livingstone. W.F.

1895—Induction Motor Connected Open Delta—In a three-phase, delta connected, squirrel-cage, induction motor having one phase of the winding internally open circuited, please explain why the machine will not run. That is, why it will not operate open delta? C.G.H. (ARIZ.)

We obtained tests on a delta connected motor with one leg of the winding disconnected, duplicating your conditions. The motor operated in a fairly satisfactory manner, having a good starting torque, and running smoothly at normal speed. It is not to be expected that this motor will carry the same load, for one third of the winding is inactive and the other two legs must carry increased current to make up. We found an unbalance in the terminal currents, one terminal carrying about 50 percent more than the other two. The flux conditions with only two active phase belts are not the best, for this arrangement gives an unsymmetrical revolving field. In fact the motor is no longer three-phase, but is two phase with current relation of 120 degrees instead of 90 degrees. We do not understand why your motor does not run, unless the motor torque under this condition is not sufficient properly to carry the load. H.L.S.

1896—Motor Overloads—Prevention of Fuses Blowing—I am employed in testing motors for a large automobile company. There is considerable trouble from fuses blowing which causes production loss. The trouble seems to be usually hard stock or work pushed too hard for a small space of time. (a) The feeders are fused to a maximum, but the fuses blow. To avoid time loss, would it be advisable to install automatic reclosing circuit breakers in the feeder circuits which blow these fuses. (b) Do you think that if a line shafting extends the length of a building on both sides, which shafting is parted in sections, using a motor from 25 to 40 hp on each section, that fuse blowing would be less and first cost and running economy be better, if larger motors were used to operate the same sections as two now or in what way would it be practical to arrange for each two sections of shafting to be driven by two motors, using some sort of slip coupling, the idea in mind being that one motor would help out the other and prevent overloads. What would you think of the advisability of placing a reactance in an alternating-current motor circuit to prevent the fuses from blowing on sudden overloads? If it is not desirable to place a reactance permanently in the motor circuit, what about having a reactance which would normally be short-circuited by a magnet switch, the magnetic switch to be opened by a relay during overloads? Since it requires a little time for a fuse to blow, it seems the magnetic inertia would not be an objection. If this is not desirable how about placing the reactance in a circuit which feeds a number of motors? T.E.M. (MICH.)

(a) It is not advisable or practical to have reactance in a circuit to prevent fuses from blowing. For the service as mentioned in the above question it is standard practice to use automatic circuit breakers with inverse time elements. (b) The first cost would be less using one large motor in the place of two of half the capacity. The running economy would be better with the larger motor if the driven machines all operate continuously, but might be less if part of them are idle some of the time. The reliability would be lessened by using one motor, as any trouble would tie up twice as much driven apparatus. We know of no practical arrangement whereby two motors may be coupled together in such a manner as to increase the reliability in driving two line shafts. With such an arrangement fuses blowing in one motor circuit would also cause the fuses in the other motor circuit to blow. If the motors did not have the same speed torque characteristics they would not divide the load equally. J.S. & T.W.

1897—Locating Grounded Coil—What is the quickest method of locating a grounded coil in a three-phase, 60 cycle, 550 volt, one circuit or two circuit star or delta connected windings? I now open the windings at the neutral point and locate the grounded phase and open this circuit at points until the grounded series is located then cut out the grounded coil. This method takes considerable time which I would like to cut down if there is a quicker method, as often a whole department is tied up pending these repairs. E.W.B. (ONT.)

An excellent method is to apply a voltage between the windings and core at as low a value as will show the grounded condition and watch for the spark. If the voltage is kept on, the point where it is grounded will smoke and can easily be found. C.W.K.

1898—Testing Transformer—Where 110 volts, 30 cycles is not obtainable, will 220 volts, 60 cycles have the same result, or is the latter too severe for testing transformers, no-voltage coils, etc? B.C. (QUE.)

We assume that this question refers to the feasibility of using a testing transformer having a low voltage winding rated at 110 volts, 30 cycles, on a 220 volt, 60 cycle circuit. No difficulty would be experienced in applying double voltage at double frequency, but the high-voltage winding might be endangered by being subjected to this 200 percent voltage and, of course, the tester would need to bear in mind that he would obtain twice the voltage marked on the high side of his transformer. If the low-voltage winding is now paralleled for 110 volts, it could be reconnected with the two halves in series and used at normal rating on the high-voltage end. The double frequency should be satisfactory for break-down tests on transformers, no-voltage coils, etc. Should the question refer to using 220 volts, 60 cycles instead of 110 volts, 30 cycles for testing the ratio of transformers and continuity of circuit in no-voltage release coils, etc., this would also be satisfactory, provided the tester is not concerned with magnetizing values. W.J.H.

CORRECTION

The following subtitle was inadvertently omitted from Fig. 6, page 238 of this issue.

Regeneration change-over contacts 41-A to D are closed in motoring only. Regeneration change-over contacts 41-E to H are closed in regeneration only. Reverser contacts 36-A-C-E-G-I-K-M-O are closed for forward movement from No. 1 End. Reverser contacts 36-B-D-F-H-J-L-N-P are closed for reverse movement from No. 1 End.

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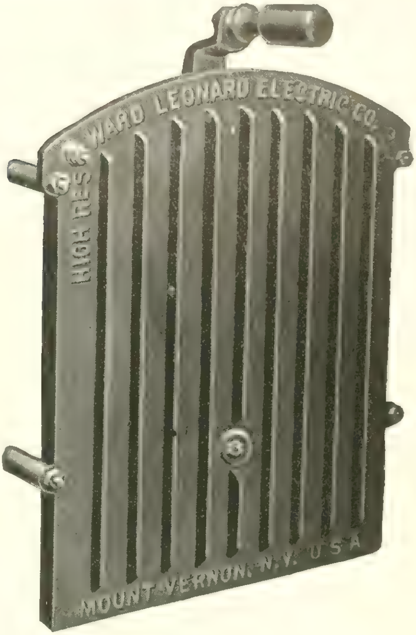
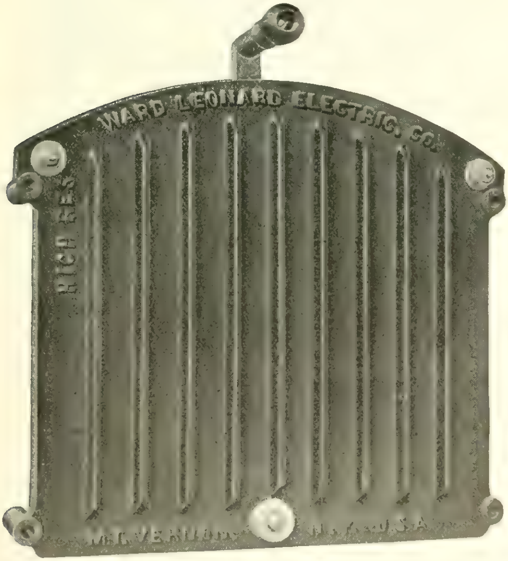
Type UR 110

is rated at 10 amperes maximum, 1 ampere minimum. Size, 14" x 14" x 4". Weight, 35 lbs. boxed. Will take care of any number of batteries from one up to the maximum which can be charged from the line supply.





Type UR 115

Charging rate 15 amperes tapers to $1\frac{1}{2}$ amperes. Size 14 in. x 18 in. x 5 in, Weighs approximately 35 lbs.

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NATIONAL SAFETY SECTION

SHOP LIGHTING

Blindfold even the most skilled mechanic and he is helpless. Any piece of work which he attempted to do would be spoiled and he would be liable to injure himself or some other workman.

Workmen in a poorly lighted factory are, in effect, partially blindfolded, the process of manufacturing goes on, but certainly not as efficiently as if adequate light were provided. Yet many manufacturers who supply their employees with the best of tools and equipment fail to consider the importance of the worker's eyes and the handicap of poor lighting. The efficiency of the workman determines the efficiency of the machine. Adequate illumination is an essential factor in securing high efficiency of the workman. Inadequate and improper illumination increases the probability of accidents. A careful analysis of 91 000 accidents showed that about twenty-four percent were due wholly or in part to poor lighting.

Natural Light—Adequate daylight illumination, properly applied, is the ideal light for the eyes. Light from above is generally better than light from side windows only. Skylights and monitor windows should, therefore, be provided wherever possible. Large window areas, equipped when necessary with awnings, window shades or blinds, and diffusive or refractive glass, together with light interiors, are desirable in every work place.

Arrangement of Work Benches and Machines—Machines and work benches should be placed to secure the best light available. Benches at right angles to wall will often be found to improve conditions. Close machine work and bench work should be placed nearest the windows and the coarser work in center of room. Machines should be so placed that the light reaches the workman from the side and falls naturally on the work, and that operators, benches, and machine interfere as little as possible with the proper distribution of light to others further from the windows. Lighting is improved by the removal of overhead belting.

Artificial Light—Artificial light is required in factories and shops on an average, about 20 percent of the total working hours, not including overtime or night work. Where night work is carried on, the artificial lighting problem must, of course, receive particularly careful consideration. The development of new and improved types of lights, in many sizes, makes it possible to secure satisfactory and adequate illumination in any industry and under varying conditions.

Requirements—(a) Sufficient illumination at the work for each man in the shop.

(b) All lighting equipment selected and installed with a view to avoiding eye strain.

(c) Lamps so placed that sharp shadows will be avoided.

(d) The overhead system of lighting employed whenever possible, thereby avoiding the use of individual lamps except for special cases.

(e) When individual lamps must be used, they should be provided with suitable opaque reflectors.

(f) The type, size and spacing of lamps and reflectors should be determined with special reference to the ceiling height and class of work in question.

Systems—In the *direct lighting system*, which is most commonly employed, the light from the lamp shines directly on the object to be illuminated. Reflectors or enclosing globes are used to improve the light distribution, and to diffuse the direct rays from the lamp.

In *indirect lighting*, the work is illuminated by light reflected from the ceiling and walls. The glare from the lamp is avoided, the reflected glare from glossy surfaces is reduced and shadows are greatly softened. Indirect lighting is the nearest approach to daylight.

Semi-indirect lighting combines the features of direct and indirect lighting systems. An opal glass bowl is used below the unit and permits a part of the direct light to pass through, while other rays are reflected to the ceiling and walls.

Local lighting alone should never be used, except for a few special operations. A moderate degree of general lighting from overhead lamps should be supplied even if local illumination is necessary at the machines; but whenever possible a system of general illumination only should be used, as this gives the most satisfactory results.

Lamps—The lamps best suited to industrial use include the incandescent lamps of the mill-type tungsten, vacuum tungsten, and gas-filled tungsten types; the mercury vapor lamp; and various types of gas mantle lamps.

Carbon filament lamps—Incandescent lamps with carbon filaments are strong and durable and, because of their ability to withstand jar and vibration, are suitable for portable service, such as for boiler repairmen. They operate at from 3.75 to 5 watts per spherical candle-power.

Mill-type tungsten lamps of special construction to withstand jar and vibration have recently been made available. These lamps are made in 25 and 50 watt sizes and operate at efficiencies of 1.4 to 1.5 watts per spherical candle-power.

Vacuum tungsten lamps may be obtained in sizes from 10 to 250 watts, and operate at efficiencies of 1.6 to 1.2 watts per spherical candle-power. In sizes up to 50 watts they are preferable for local lighting.

Gas-filled tungsten lamps are made in sizes from 75 to 1000 watts. Their efficiency varies with the size of the lamp, from one watt per spherical candle-power for small sizes to 0.7 for the large sizes.

Mercury-vapor lamps are often used in such industries as metal working plants, textile mills and printing establishments. Because the luminous surface is large (a long tube about one inch in diameter) the brightness is low and less care in shading is required than with other lamps. The mercury vapor lamp is supplied by only one manufacturer, who designs each installation of his product. Data on the use of these lamps is, therefore, not included in this article.

Gas lighting has formerly been handicapped by lack of adaptability, difficulty of maintenance and poor planning. Recent developments in efficient mantle gas units, equipped with well designed reflectors, are worthy of consideration.

Reflectors—About two-thirds of the light from a bare incandescent lamp goes horizontally or upward and is useless for direct lighting. With a flat cone reflector about one-third of the light goes horizontally and is wasted. An efficient reflector reduces the glare caused by looking at a bare lamp, and redirects the greater portion of the light onto the work. Reflectors, both metal and glass, are now obtainable for all sizes and types of lamps. For a certain ratio between the spacing and the height of the lamps, a reflector can nearly always be selected which will furnish uniform illumination over the working plane. For industrial lighting five distinct types of reflectors are here considered. Their relative advantages and disadvantages are shown in the table below.

Illumination intensity is expressed in foot-candles. One foot-candle is the intensity of illumination produced on a surface one foot distant from a lamp of one candle-power, the surface being at a right angle to the light rays. Different industries, and different operations in the same industry, require varying intensities of illumination. The useful light is that which is reflected from the object viewed. The brightness of the object then is the vital factor, and this depends not only on the light received, but upon the reflecting power of the object. Materials vary greatly in reflective power; white surfaces reflect as high as 80 percent of the light, while black surfaces reflect less than five percent. It is, therefore, important to consider the average reflecting power of the materials worked upon, as well as the nature of the work, whether rough or fine. The following table is in line with the recommendations of state labor departments and the Illuminating Engineering Society. The lower intensities given are considered sufficient for safety, but the higher values are recommended from the standpoint of efficient production.

To be continued

WHAT THE NATIONAL SAFETY COUNCIL IS

The National Safety Council, 168 North Michigan Avenue, Chicago, Ill., is now the leading organization in the United States for the prevention of accidents in the industries, the streets and the homes. It includes in its membership more than 15 000 factories, railroads, insurance companies, technical schools, governmental agencies, etc., employing an aggregate of more than 6 000 000 workers. Its income is derived solely from membership dues. It does its work without asking for profit. It is co-operative, non-political, non-commercial. Practically all the industrial concerns, railroads and other public utilities, both large and small, which have obtained the best results in accident prevention are members of the National Safety Council.

You Cannot Buy It

You cannot buy the accident prevention service of the National Safety Council. As a member you automatically acquire all of the Council's thoroughly organized weekly service. And its accumulation of data and statistics, its magnificent experience, is yours to use at will—in facilitating the safety effort of your plant.

The National Safety Council was organized as a co-operative association with the sole object of assisting member plants to prevent accidents. The National Safety Council today, while greatly increased in size, is still operating as a purely co-operative, non-profit-making association with the same objective—accident prevention—as its goal.

It has forced recognition as the headquarters of safety activity in America through its achievements—which stand as mile-posts in the history of accident prevention.

What its service has helped others to accomplish, it can help you to accomplish. Write the business division for details today.

National Safety Council

Co-operative ***Non-commercial***

168 N. Michigan Avenue, Chicago, Illinois

PERSONALS

Gen. Guy E. Tripp, chairman of the board of directors of the Westinghouse Electric & Mfg. Company, has been elected a director of the American Water Works & Electric Company of New York.

Dr. F. O. Cottrell, chief metallurgist, Bureau of Mines, has been appointed to succeed Dr. V. H. Manning as director of the bureau.

The Emperor of Japan has decorated with the order of the Rising Sun, Mr. E. M. Herr of Pittsburgh, president of the Westinghouse Electric & Mfg. Company and Mr. L. A. Osborne of New York, president of the Westinghouse Electric International Company, who have been spending several months in Japan studying oriental industrial conditions.

Mr. W. S. Finlay, Jr., superintendent of motive power of the Interborough Rapid Transit Company, has resigned to accept the position of vice-president of the American Water Works & Electric Company of New York.

Mr. C. D. LaMoree, manager of the supply division of the Los Angeles district office of the Westinghouse Electric & Mfg. Company, has resigned to go into business in the newly formed concern, LaMoree & Clapp, Inc.

Mr. John C. Jones, manager of the Salt Lake City office, has been transferred to the Los Angeles office as manager of their supply department.

Mr. Wilfred Sykes, general engineer on steel mill and marine work for the Westinghouse Electric & Mfg. Co., has resigned to enter the employ of the Steel & Tube Co. (formerly Mark Mfg. Co.) of Chicago.

Mr. Myles B. Lambert, recently appointed manager in charge of the railway sales department of the Westinghouse Electric & Mfg. Company, has announced the following appointments: Mr. W. R. Stinemetz has been appointed manager of the heavy traction section, including the Westinghouse Electric International and the Canadian Westinghouse Company, Ltd.; Mr. E. D. Lynch has been appointed manager of the light traction equipment section; Mr. J. L. Crouse has been appointed manager of the railway apparatus development and supply section and Mr. K. A. Simmon has been appointed manager of the safety car and foreign railway equipment section.

Mr. B. W. Stemmerich of the railway equipment section of the Westinghouse Electric & Mfg. Company at East Pittsburgh, has been transferred to the St. Louis District office where he will be in charge of the safety car division.

Mr. Paul Kircher, resident manager of the Massey Concrete Products Corporation for the New York district, has been made resident manager of the Chicago office in charge of sales of reinforced concrete poles which this Company manufactures, by the centrifugal process.

Mr. Wm. H. Boyce, who has been superintendent of the Beaver Valley Traction Company and the Pittsburgh & Beaver Street Railway Company since 1909, has been appointed general manager of both these properties and will maintain offices in both New Brighton and Beaver Falls.

Mr. H. C. Soule of the transformer engineering department of the Westinghouse Electric & Mfg. Company at East Pgh., has been appointed manager of the Apparatus Department of the Westinghouse International Company with headquarters at East Pittsburgh.

Mr. H. F. Griffith, formerly of the export department of the Westinghouse Electric & Mfg. Company, has been appointed assistant to general manager of the Westinghouse Electric International Company whom he will represent at East Pgh. works.

NEW N. E. L. A. OFFICERS

At the Pasadena convention of the National Electric Light Association the following officers were elected for the ensuing year:—

President—Martin J. Insull, Middle West Utilities Co., Chicago; 1st vice-president—M. R. Bump, Chief Engineer, H. L. Doherty & Co., New York; 2nd vice-president—Frank S. Smith; 3rd vice-president—Walter H. Johnson, Philadelphia Electric Co.; 4th vice-president—F. T. Griffith, Portland Electric Light & Railway Co.; treasurer—H. C. Abell, American Light & Power Company, New York.

The executive committee is composed of the following:—E. M. Herr, Westinghouse Electric & Mfg. Company, Pittsburgh; Paul Spencer, United Gas Improvement Co., Philadelphia; E. W. Rice, General Electric Company, Schenectady; R. H. Ballard, Los Angeles, California; W. H. Atkins, Boston Edison Company; E. W. Loyd, Commonwealth Edison Co.; P. H. McDougall, Toronto Electric Light Co.; R. B. Layman, Wagner Electric Mfg. Co., St. Louis, Mo.

The committee on membership report a total of considerably over 10 000 members.

A. I. E. E. ELECTION

At the annual business meeting of the American Institute of Electrical Engineers, May 21st, the following officers were declared elected for the year beginning August 1st, 1920:—

President

A. W. Berresford, Milwaukee

Vice-Presidents

E. H. Martindale, Cleveland.
Charles Robbins, Pittsburgh.
Charles S. Ruffner, New York.
C. E. Magnusson, Seattle.
C. S. McDowell, U. S. Navy.
L. T. Robinson, Schenectady.

Managers

E. B. Craft, New York.
Harold B. Smith, Worcester.
James F. Lincoln, Cleveland

Secretary

F. L. Hutchinson, New York

Treasurer

George A. Hamilton, Elizabeth, N. J. (re-elected)

The above, together with the following hold-over officer, will constitute the Board of Directors for the next administrative year:—Calvert Townley, New York; Comfort A. Adams, New York; Walter A. Hall, Atlantic, Mass.; William A. Del Mar, New York; Wilfred Sykes, Pittsburgh; Walter I. Slichter, New York; G. Faccioli, Pittsfield; Frank D. Newbury, Pittsburgh; L. E. Imlay, Niagara Falls; F. F. Fowle, Chicago; L. F. Morehouse, New York.

NEW BOOKS

"Electrical Power Transmission" —Alfred Still. 403 pages, illustrated. Published by McGraw-Hill Book Co. For sale by the Electric Journal, Pittsburgh, Pa. Price $3.00.

This is the second edition of this work originally published in 1913 under the title "Overhead Electric Power Transmission." It is primarily a text book for engineering schools. The principle addition is a chapter on underground conductors. While some of the material in the first edition has been entirely omitted, the chapter describing the Thury system of transmission is retained for general information although American engineers have made no use of this system. The discussion on transmission line supports brings together some information which has not been generally available in book form and includes discussions on flexible tower lines.

The chapters on "Economic Principles" and on "Mechanical Principles and Calculations" are especially valuable. Prof. Stills book has always been considered one of the leading textbooks on this general subject, and the revised edition fully maintains its previous reputation.

"How to sell Electrical Labor Savings Appliances"—115 pages, size 5x7½ inches, illustrated. Published by McGraw-Hill Book Co., New York City. Price, $1.00.

This book presents 119 plans for making sales in electrical stores, covering window displays, show cases, shelves and tables, arrangement of stock, advertising, methods of securing prospects and making demonstrations, how to train clerks and plan sales, also methods of management. These plans are based on actual experience and in many cases the concerns having had the experience with a given plan are indicated.

"Oil Engines"—Lacey H. Morrison. 472 pages, 357 illustrations. Published by McGraw-Hill Book Co., Price $2.00.

This book is primarily for operating men and contains descriptions and instructions regarding the various forms of oil engines available as well as the various forms of fuel being used by internal combustion engines. An introductory chapter is given on the history of gas engines, followed by one on the Diesel type engine with descriptions of the various forms of American engines built on the Diesel principle. Chapters are also given on installation, main bearings, connection rods, pistons, piston pins, cylinders, cylinder heads, valves fuel pumps and governors. Various methods of cooling and systems of lubrication are described and the final chapters are devoted to such items as fuel consumption and operating details.—

NEW BOOKS

"Principles of Government Purchasing" —A. G. Thomas. 270 pages, 6 by 9 inches. Published by D. Appleton & Company. For sale by The Electric Journal. Price, $2.25.

This volume is one of a series of studies of different branches of administration, fostered by the Institute for Government Research. The Government makes its purchasing under strict specifications and must comply with particularly formal procedure in the placing of contracts and in their final approval and payment. The many requirements underlying the entire subject are extensively treated by the author; such as restrictions under which contracts may be made determining quantities, market prices, sources of supply, developing specifications and carrying through to final inspection for payment. E.D.D.

"Selling Your Services"—Geo. Conover Pearson. 237 pages. Published by Jordan-Goodwin Corp., Jefferson Bank Bldg., New York, N. Y. Price $2.00 prepaid.

Knowing that the fundamental principles that are effective in selling any product apply also to selling a man's services, Mr. Pearson has given, in simple and useful form, plans for conducting a resultful campaign for selling one's own service. The book is filled with practical examples of letters, advertisement and telegrams. One point brought out is that a man should consider the securing of a new position as his job and should have regular hours and devote his time to this work just as though he was regularly employed by some corporation in selling its product. The book is presented in a form which will be interesting even to those who may not be in immediate need of it as a means of securing a position.

"Electric Lighting"—O. J. Ferguson. 243 pages, 104 illustrations. Published by McGraw-Hill Book Company. For Sale by The Electric Journal. Price $2.50.

The aim of the author in this case is a textbook covering this subject in a well-balanced form through the presentation of fundamentals, with practical applications as thought desirable. The result, while suitable for the use of young students, is not so satisfactory for the older searcher after information on this subject, as naturally it is impossible to go very deeply into any particular phase of the subject. A good chapter is given on illumination calculations.

"A Calender of Leading Experiments"—W. S. Franklin and Barry MacNutt. 210 pages, 107 illustrations. published by Franklin, MacNutt & Charles, South Bethlehem, Pa. Price $2.50.

From beginning to end this book is filled with semi-humerous reflections on the problems of the teacher of physics. Numerous experiments are given under the headings Mechanics, Heat, Electricity and Magnetism, Light, Sound and a Simple Treatise on Dynamics of Wave Motion. An Appendix is included on a Visitor's Laboratory of Physics.

TRADE NOTES

The Electric Storage Battery Company have announced the removal of their Cleveland office to Chester Avenue and East 24th St., where they will have the entire second floor of the "Exide" Battery Service Station.

The H. B. Sherman Mfg. Company of Battle Creek, Michigan, issue their bulletins in convenient loose leaf form with an attractive binder. This firm makes a large variety of terminals and connectors for electrical work, including fuse clips, soldering lugs, etc. They also have a Sherman ground clamp, approved by the Underwriters. Their various devices are made in numerous sizes and those interested in electrical construction work should have their loose leaf catalogue on "Electrical Goods", available. Copies will be sent on request.

The Delta-Star Electric Company, 2433 Fulton Street, Chicago, are distributing their special publication No. 93 illustrating unit-type outdoor high tension substations for industrial service. Copies of this publication will be sent upon request.

The Bates Expanded Steel Truss Company of Chicago, Illinois, designers and manufacturers of the Bates One Piece Steel Pole, have just published a 128 page 1921 Edition of their Steel Pole Treatise. This treatise is a compact engineering handbook of inestimable value to engineers and pole users of the world. It contains accurate information necessary to the economical construction of modern transmission lines, electric railway lines, street lighting systems and outdoor substations. The information includes a discussion of the engineering principles governing the design, selection and installation of all types of poles, a complete analysis of the elements governing the selection of factors of safety, a comparison of the length of life, economy and durability of Bates one piece poles with all other types of poles, and complete engineering tables. These tables include wire sags for all temperatures and spans, the conductor sizes required to transmit electric power various distances at any phase, voltage, frequency and power factor, the transverse loads at various wind velocities, the clearances to determine the height of a pole, physical properties of wires and cables, and many useful formulae and example problems illustrating the use of the tabulated information in the solution of all pole line problem. This edition is the most complete and accurate steel pole handbook ever issued, and is an authority upon pole line construction. It will be sent free to all those requesting a copy.

The Electric Storage Battery Company has removed its New York offices to the National Association Bldg., at 21 West 43rd St., where larger quarters and more adequate facilities are available for properly caring for customer needs. The former offices at 100 Broadway had been occupied for approximately 25 years.

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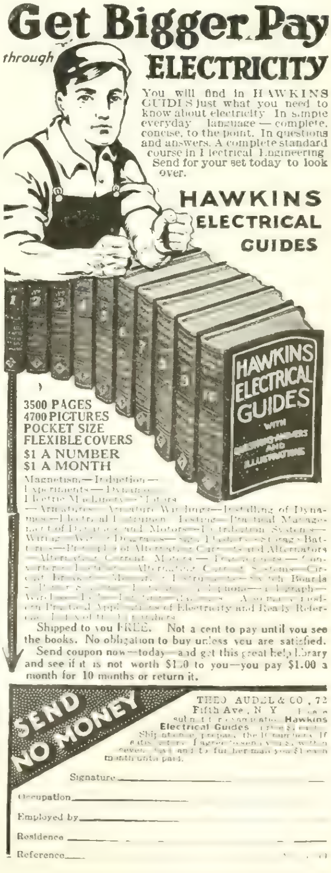

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EXCEPTIONAL VALUES

Alternating Current Motors

3 Phase, 60-Cycle, 40° Rating

No.	HP.	RPM.	Volts	New or used	Type	Make
4	8	1800	220 or 440	new	AN	Allis Chal.
7	5	1800	220 or 440	new		Ideal
18	5	1200	200 or 440	new		Ideal
4	7½	1200	220 or 440	new	AN	Allis Chal.
1	7½	1800	220 or 440	enw	AN	Allis Chal.
6	10	1800	220 or 440	new	AN	Allis Chal.
5	10	1200	220 or 440	new	AN	Allis Chal.
2	10	900	220 or 440	new	AN	Allis Chal.
1	15	1800	220 or 440	new	AN	Allis Chal.
5	15	1200	220 or 440	new	AN	Allis Chal.
2	15	900	220 or 440	new	AN	Allis Chal.
1	15	860	220 or 440	new	AN	Allis Chal.
1	15	860	220	used	CS	Westghse
8	20	1800	220 or 440	new	AN	Allis Chal.
8	20	1200	220 or 440	new	AN	Allis Chal.
1	20	900	220 or 440	new	AN	Allis Chal.
8	25	900	220 or 440	new	AN	Allis Chal.
1	80	1800	220 or 440	new	AN	Allis Chal.
8	80	1200	220 or 440	used	AN	Allis Chal.
1	80	1200	220 or 440	new	AN	Allis Chal.
6	80	900	220 or 440	new	AN	Allis Chal.
1	80	700	220	used	BP	Wagner
1	80	900	220 or 440	used	AN	Allis Chal.
2	40	1200	220 or 440	new	AN	Allis Chal.
1	40	1700	2200	used	CCL	Westghse
8	40	900	220 or 440	new	AN	Allis Chal.
2	50	1200	220 or 440	new	AN	Allis Chal.
4	50	900	220 or 440	new	AN	Allis Chal.
1	50	720	220 or 440	new	AN	Allis Chal
5	75	900	220 or 440	new	AN	Allis Chal.
1	100	1200	2200	new	CS	Westghse
8	100	900	220 or 440	new	AN	Allis Chal.
2	100	720	220 or 440	new	AN	Allis Chal.
1	100	690	220 or 440	new	AN	Allis Chal.
2	150	900	220 or 440	new	AN	Allis Chal.
1	150	720	2200	new	AN	Allis Chal.
1	200	1200	2200	new	AN	Allis Chal.
1	200	720	220 or 440	new	AN	Allis Chal.
1	200	580	440	used	CS	Westghse

Alternating Current Motors, Slip Ring

3-Phase, 60-cycle, 40° Rating

No.	HP.	RPM.	Volts	New or used	Type	Make
2	30	1800	440	used	HF	Westghse
2	30	900	220 or 440	new	ANY	Allis Chal.
3	50	900	220 or 440	new	ANY	Allis Chal.
1	100	900	220 or 440	new	ANY	Allis Chal.
2	100	720	220 or 440	new	ANY	Allis Chal.
1	150	900	2200	new	ANY	Allis Chal.
1	150	720	220 or 440	new	ANY	Allis Chal.
1	155	720	440	new		Burke
1	200	720	2200	new	ANY	Allis Chal.

Direct Current Motors

230 Volts.

No.	HP	RPM.	Wdg	Type	Make
1	¼	975	sh	MP	Peerless
2	¼	1000	sh	B	Akron
1	2½	700/900	sh	S	Westghse
1	3½	975	cp	B-5	Milwaukee
1	4	1200	sh	MP	Christensen
1	7½	500/1500	sh	SK	Westghse
1	7½	1300	cp	B-7	Milwaukee
1	7½	825	sh	13	Milwaukee
1	7½	825	cp	MP	Milwaukee
1	7½	950	cp	K	Allis Chal.
1	10	1180	sh	S	Westghse
1	10	750	cp	B-10	Milwaukee
1	13	1750	sh	SL	C & C
1	20	800	sh	MP	Imperial
1	20	600	sh	MP	West'n Elec.
1	20	600	sh	MP	Westghse
1	20	650	sh	MP	Northern
1	20	650	sh	MP	Milwaukee
1	20	900	sh	MP	Hobart
1	22	1050	cp	B-51	Milwaukee
1	22	1050	cp	B-15	Milwaukee
1	25	1300	sh	B-15	Milwaukee
1	30	975	sh	MP	Gen. Elec.
1	30	350/1050	sh	SK	Westghse
1	35	1600	sh	ENC	West'n Elec.
1	40	950	sh	B-25	Milwaukee
1	40	675	sh	MP	Northwstrn
1	40	918	cp	MP	Jenny
1	50	525	cp	MP	Northern
1	55	845	sh	B	Gen. Elec.
1	75	800	cp	A-50	Milwaukee
1	90	1000	cp	A-50	Milwaukee
1	90	1000	cp	MP	Milwaukee
1	95	575	cp	MP	Jenny
1	105	890	cp	DLC	Gen. Elec.
1	115	1000	cp	DLC	Gen. Elec.
1	650	315	sh	MP	Burke
1	800	315	sh	MP	Burke

Direct Current Engine Generator Sets

250 Volts.

1—56 KW. 250 V. Milwaukee generator, belted to Ball Steam engine. 90 HP. 100 to 125 lb. steam pressure, complete with all accessories.

2—75 KW. 250 V cp wd. 290 RPM. Westinghouse generator, direct connected to 125 HP. Automatic Westinghouse steam engine, complete with all accessories.

1—75 KW. 125/250 V. 3 wire cp. wd. Western Electric generator, direct connected to Ball Steam engine. 100 to 125 lb. steam pressure.

1—75 KW. 250 V. General Electric Generator, Type MP 230 RPM, direct connected to Nash Gasoline Engine, manufactured by National Meter Company, complete with all piping tanks and accessories.

1—80 KW. 250 V. Gen. Electric, cp. wd. Type DLC generator, belted to 125 HP. 100 to 125 lb pressure, Lord Howler Steam engine, complete with all accessories.

2—100 KW. 250 V. cp. wd. 325 RPM Northern Generators, belted to 16 x 22 side crank non condensing 125 RPM Slide Valve Single engine, manufactured by Houston Stanwood & Gamble, complete with all accessories including belt.

1—150 KW. 250 V. cp. wd. 8 pole 210 RPM Goodman Generator, direct connected to

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THE ELECTRIC JOURNAL

VOL. XVII JULY, 1920 NO. 7

International Standardization

The desirability of international standardization should be so evident to all that no argument to this effect should be necessary. The bringing about of international standardization is, however, quite a different matter, as national standardization is in itself difficult and the difficulties are increased when international standardization is undertaken.

These difficulties are due mainly to the fact that various local and national standards and practices different from each other have grown up by process of evolution, becoming so much a part of local or national business that any modification or change involves difficulty and expense. As a rule, the enforcement of standards which are different from existing practices causes confusion and expense, until the new completely replace the old standards and practices. Those having to do with either national or international standardization must therefore consider whether or not, in the end, the results to be achieved will overbalance the temporary expense and difficulty due to bringing such standardization into actual practice. In the consideration of any particular standard, this requires the looking ahead for a number of years and the making of such compromises as will ultimately result in the most benefit.

In international standardization, it is therefore desirable to deal with fundamental principles, so far as possible, and to leave details to be worked out by the various countries which take part in such standardization. It was along this line that the Rating Committee of the International Electro-technical Commission attempted to work in the meeting held in Brussels, Belgium, the latter part of March of this year. This meeting was attended by representatives of nine different countries, the United States being represented by five delegates. Agreements of very considerable importance were arrived at, particularly with regard to the basis of temperature ratings of electrical machines. Good progress was also made in connection with the standardization of symbols and nomenclature, and in regard to standard voltages for transmission lines. The actual details and results will appear shortly in a publication to be issued by the General Secretary of the International Electrotechnical Commission, 28 Victoria Street, Westminister, S. W. 1, London. The place of the next plenary meeting was not fully decided but it will probably be held late this fall either in Paris or New York. Those who were privileged to attend the meeting in Brussels can testify to the value of the work so far accomplished and one and all can join in expressing appreciation to the Belgian National Committee for the various arrangements made for the comfort and entertainment of the delegates. C. E. SKINNER

Appliance Outlets

The need of appliance outlets in American homes cannot be too strongly emphasized. The maximum use of labor saving devices, electric cooking utensils, decorative lamps and other current using devices cannot be obtained unless their use is made convenient, which is only possible through the liberal installation of floor or wall sockets. While this is generally recognized as desirable, the idea should be emphasized in every way possible until the appliance outlet becomes as common as the ceiling outlet.

The central station cannot urge such a campaign too strongly, while their rates penalize those installing numerous outlets. It is obviously inconsistent to urge the installation of extra appliance sockets, and then place a tax on the installation of such sockets by an ill-advised form of maximum demand rate. The demand feature is logical and desirable if properly adjusted. Where the installation of a demand meter is impracticable there are various ways of estimating demand which are effective. Basing the demand on the outlets installed, however, tends to defeat the prime object of encouraging the use of current consuming devices. The inadvisability of estimating the maximum demand upon such a basis would seem so obvious as to be hardly worthy of comment, were it not such common practice.

CHAS. R. RIKER

The Trail of the Pioneer

Blazing paths into the unknown, whether in the field of geography or science, is the lot of the comparatively few, who are fitted by nature and by training to act the part of pioneers. Most men must be content to travel along the routes which have been pointed out by others. The success of the pioneer is measured not alone by the importance of the new fields which he discovers, but also by the extent to which he and his associates clear the pathway so that others may follow.

The modern scientist is no less a pioneer because he uses mathematical expressions rather than an axe. His success is measured by the way in which he provides that other men, less gifted than he, may attain the same goal. An example of this type of scientific road making is provided by the charts which are published by Mr. Nesbit in this issue of the Journal, wherewith Dr. Kennelly has blazed a broad trail through the jungle of hyperbolic functions, which any engineer, though previously unacquainted with this form of mathematics, may follow with ease. The thanks of every engineer who has to deal with transmission problems are due to Dr. Kennelly and Mr. Nesbit for this simplification of an exact method of calculation.

3000 Volt Current Collectors

For the Chicago, Milwaukee & St. Paul Locomotives

A. Schaake

THE COMBINATION of a double shoe type of pantagraph trolley and a twin-wire flexibly-supported catenary overhead construction has very effectually solved the problem of heavy current collection. The sliding shoe type of pantagraph has been used extensively for high-voltage, single-phase current collection since 1905. The current values are low, however, compared with direct-current operation. The possibilities of collecting heavy currents from an overhead trolley wire were not generally recognized until the electrification of the Niagara Junction Railway at Niagara Falls in 1913. At this time a pantagraph trolley was developed having two flexibly mounted contact shoes, which were made of sheet steel with copper wearing strips.

The majority of electrified railroads taking direct-current from an overhead wire at this time were using either a wheel trolley or a pantagraph trolley with a heavy roller for collecting the current. Neither the wheel trolley or the roller pantagraph are suitable for high-speed, heavy electric traction. The wheel trolley cannot be controlled from the cab and has a tendency to leave the wire. The roller pantagraph is fairly satisfactory with currents less than 300 amperes and speeds less than 35 miles per hour. The limited contact area prohibits the collection of heavy currents and the weight and inertia of the roller cause excessive sparking and flashing at high speeds.

The satisfactory operation of the double shoe pantagraph resulted in its adoption by the Chicago Milwaukee & St. Paul Railroad for the original electrification, and this pantagraph, with several modifications, has been applied on the new passenger locomotives.

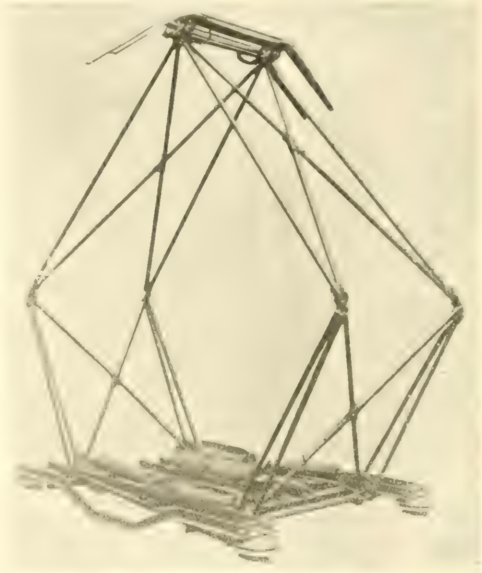


FIG. 1—PANTAGRAPH TROLLEY RAISED

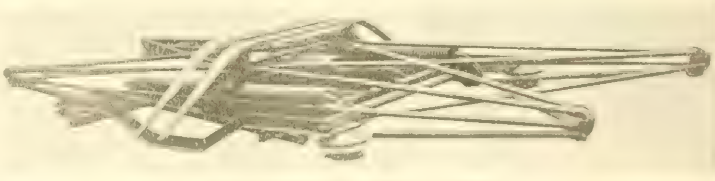


FIG. 2—PANTAGRAPH TROLLEY LOWERED

Pantagraph trolleys are divided into two classes:—air raised; and air lowered. In the air raised trolley, the continued application of compressed air is necessary to hold up the trolley. In the air lowered trolley, the application of compressed air is required only to lower the trolley and to disengage an automatic latch. The large majority of pantagraphs in this country are of the spring raised type, whereas in Europe the majority of pantagraph trolleys are air raised.

The Pantagraph trolley which has been adopted by the Chicago, Milwaukee & St. Paul Railroad is of the air raised type. The principle elements of this pantagraph trolley are:—

1 The contact shoes.
2 The movable frame work.
3 The insulated base with operating mechanism.

The contact shoes of the original Niagara Junction trolley were four feet long over the flat portion, but were shortened in the present design, due to tunnel requirements, to two feet and the overall length and drop of the horns was increased.

In collecting heavy currents, a good low resistance contact with the trolley wire is necessary. This is obtained by copper wearing strips. By having these wearing strips located on flexibly mounted shoes, equalization of contact is obtained, so that at all times current is collected from four contacts. The weight of the contact shoes has been reduced to a minimum to reduce inertia when operating at high speeds. In this way it is not necessary for the whole moveable frame of the trolley to respond to slight irregularities in the trolley wire, and this helps to eliminate sparking. The spaces between wearing strips are filled with a lubricating mixture, consisting of two parts of motor grease and one part of flake graphite. This lubrication reduces the frictional wear of trolley wire and wearing strips. Each contact shoe has two inches independent movement vertically, and the shoes are located at a maximum distance of 12 in. and a minimum distance of 9.75 in. apart center to center during this movement. An average contact pressure of fifteen pounds per shoe produces best results. More wear results from a ten pound pressure due to incipient arcing, which disappears with increased pressure.

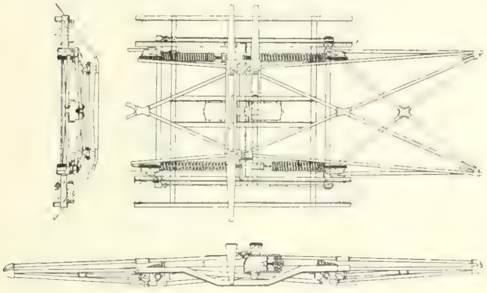


FIG. 3—PLAN VIEW OF PANTAGRAPH TROLLEY

MOVABLE FRAME WORK

The movable frame work which carries the contact shoes is made of high carbon seamless steel tubing 1.25 in. in diameter. The tubing for the upper members has a wall 1/32 in. thick and for the lower member 1/16 in. thick. Both upper and lower members are cross braced, thus making a structure which is very stiff laterally and well adapted for resisting sidesway.

The members in the upper frame are subjected almost entirely to compressive strains. It has been found that seamless steel tubing is best adapted for resisting these strains with minimum weight. The side members of the lower frame are subjected to severe bending moment and an arm is therefore built up of tubing in which the lower member is in compression and the upper member is in tension. The two sides of a lower frame are held together with a cross shaft two inches in diameter and also by two diagonal cross braces. The cross shaft is found to be an important element in reducing sidesway. Sidesway of the upper members is transmitted to the lower side members and tends to make the end of one side member to go up while the opposite member goes down. This produces a twisting moment on the cross shaft which must be heavy enough to resist this twisting moment or decided sidesway of the upper frame will result. The members of the frames are connected together by means of malleable iron castings made of the lightest possible weight consistent with strength.

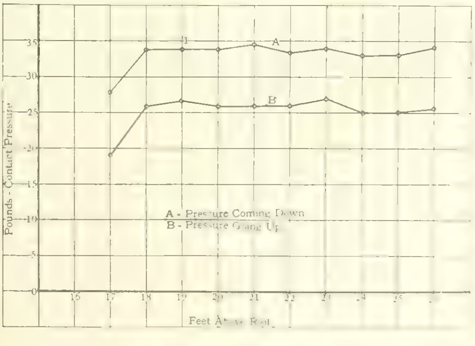


FIG. 4—TROLLEY PRESSURES

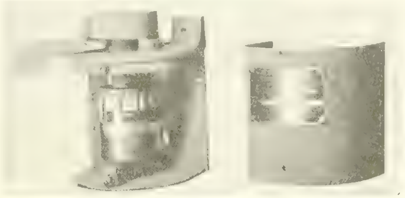
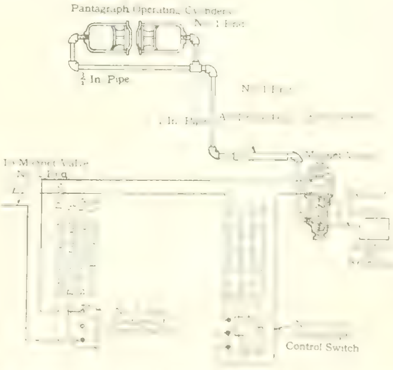


FIG. 5—PANTAGRAPH TROLLEY CONTROL SWITCH

INSULATED BASE WITH OPERATING MECHANISM

The insulated base on which the movable frame is mounted is made of 2 by 2 by ¼ in. angle iron. The base is provided with two air cylinders and necessary shafts and levers. In Fig. 4 the plan view shows the operating mechanism consisting of four tension springs, together with link chain and cam, air cylinders, etc. In the operation of the trolley, air is admitted to the air cylinder. This forces the piston against a lever and turns a shaft which connects to a second lever connected to a tension spring. The other end of the tension spring is connected to the operating cam by means of a link chain. When the piston is at the end of its stroke, the spring has been fully extended and the movable frame will rise to its maximum height. The piston then simply forms an anchor point for the spring end and remains stationary. The springs controlled by the air cylinder are located diagonally opposite each other. On the opposite side of the frame from the cylinder controlled springs are balancing springs which aproximately balance the dead weight of movable parts.



[illegible] OF PANTAGRAPH CONTROL

In this way the size of air cylinders is reduced and the balancing springs also serve to bring the movable parts to rest without a severe slam. Only small compression springs are required for a final cushioning effect.

The spring tension is applied through a link chain to a cam and in this way at every height of the trolley wire a turning moment is imparted to the pantagraph frame which counterbalances the sum of the various moments of the movable frame, contact shoe and pressure and a nearly uniform pressure on the trolley wire is obtained throughout the range of operation.

Fig. 5 shows the contact pressure for two shoes. The difference in pressure equals one-half the friction of the trolley, which is about four pounds, measured at the contact shoes. An air pressure of not less than 60 pounds per sq. in. is required to hold the trolley in operating positions. In order to lower the trolley the air is exhausted from the air cylinders.

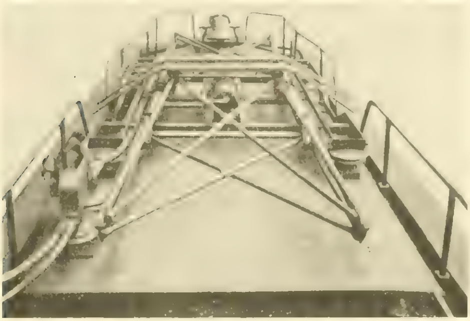


FIG. 7—PANTAGRAPH MOUNTED ON INSULATED PLATFORM

ACCESSORIES

In order that the lowering of the pantagraph may be accomplished in as short a time as possible, an electro-pneumatic valve is located at each end of the locomotive cab near the trolley and the operation of the valve is controlled by the control switch shown in Fig. 5. With this switch, either or both pantagraphs can be lowered, depending on the position of the switch handle. The contact shoes will reach the trolley wire four seconds after moving the switch handle. For lowering 2.5 seconds are required. The piping and wiring are shown in Fig. 6. It is necessary to have large pipe and air hose as shown in Fig. 6 in order that the exhaust of air may be as rapid as possible, otherwise the lowering action is retarded. It is essential that the lowering be as rapid as possible, in order that, if an obstruction occurs in the trolley line, the pantagraph may be lowered and thus avoid a wrecked trolley.

There are two trolleys per locomotive, but only one is normally used for current collection. The other trolley is held in reserve for emergency in case of a wreck or damaged trolley. When hauling a 960 ton train up a heavy grade, a current of 1000 to 1200 amperes will be collected at a speed of 20 to 25 miles per hour. At a maximum speed of 65 miles per hour a current of 300 to 400 amperes are required by this locomotive. Much heavier currents could be handled at this speed. The trolley wire is at a maximum of 26 ft. and a minimum of 17 ft. above the rail. The collapsed height of the shoe is 16 ft. 7⅞ in. above the rail.

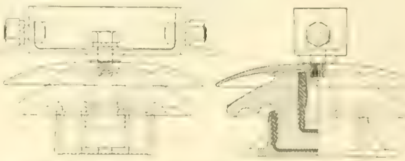


FIG. 8—INSULATORS FOR SUPPORTING PANTAGRAPH AND PLATFORM

As an additional safety feature, the pantagraph trolley sets on an insulated platform, shown in Fig. 7, made of sheet steel and channel iron. The insulators for this platform are the same as used for the pantagraph trolley, and are shown in Fig. 8. In case one pantagraph is damaged, parts of the frame might touch the roof. If the other pantagraph is raised a short-circuit would result burning a hole in the locomotive roof. The insulated platform eliminates the possibility of accidents of this sort.

OVERHEAD SYSTEM

Energy is supplied to the Chicago, Milwaukee & St. Paul locomotives by means of two 4/0 hard drawn copper trolley wires, located at a maximum height of 26 ft., normal height of 24 ft. and minimum height of 17 ft. above the rail. The two trolley wires are suspended from a common messenger cable by means of the alternate type of suspension, as shown in Fig. 10.

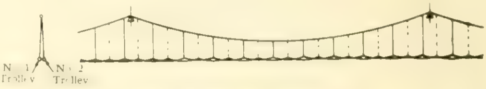


FIG. 10—CATENARY SUSPENSION

The catenary hangers are looped over the messenger cable so that the trolley wires respond very readily to the pressure of the contact shoe and a maximum of flexibility is obtained from the conductor. The hangers shown in dotted lines are for No. 1 trolley, those shown full are for No. 2 trolley wire.

Switchboard Meter Connections for Alternating-Current Circuits-VII

Measuring Reactive Volt-Amperes in a Three-Phase Three-Wire Circuit

J. C. Group

MEASURING reactive volt-amperes is comparatively simple in a two-phase circuit because of the existence in the circuit of a voltage which is normally at right angles to the current at unity power-factor. In a three-phase circuit, however, it is necessary to produce a suitable voltage by a combination of the three-phase voltages.

Connections for measuring the reactive volt-amperes in a three-phase three-wire circuit with a polyphase wattmeter of standard calibration are shown in Fig. 76. Two standard current transformers and two special voltage transformers are necessary. The secondaries of the voltage transformers must be designed for $2/3 \sqrt{3}$ (approximately 115 percent) times the nominal secondary voltage, with a tap taken out at the middle of the winding. By the nominal secondary voltage is meant a simple multiple of the rated primary voltage as determined by the ratio of transformation. Standard voltage transformers are so designed that the nominal secondary voltage is 100. In Fig. 76 the outside leads of the voltage transformers are designated as the 115 percent taps and the middle leads as the 57.5 percent taps.

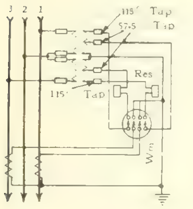


FIG. 76—CONNECTIONS FOR MEASURING REACTIVE VOLT-AMPERES

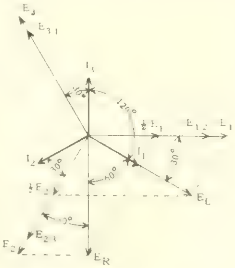


FIG. 77—BALANCED LOAD AT UNITY POWER-FACTOR

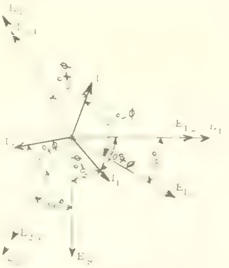
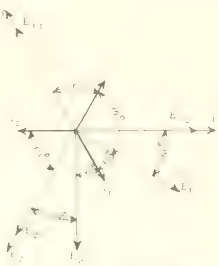


FIG. 78—BALANCED LOAD [illegible] BY AN ANGLE θ



[illegible] 30 DEGREES

This special voltage arrangement can be explained more easily in connection with Fig. 77, which shows a vector analysis of the circuit for a balanced load at unity power-factor. $E_{1\,2}$, $E_{2\,3}$ and $E_{3\,1}$ represent the three-phase line voltages, and also the nominal voltages on the secondary side of the voltage transformers or, as considered above, the voltages corresponding to 100 percent. E_1, E_2 and E_3 represent the actual voltages on the secondary side of the voltage transformers, or the voltages referred to as 115 percent. $1/2\,E_1$ and $1/2\,E_2$ represent the voltages between the middle points of the secondary windings and an outside lead respectively of the two voltage transformers. I_1, I_2 and I_3 represent the line currents and also the currents on the secondary side of the current transformers.

In a three-phase three-wire polyphase wattmeter, for a balanced load at unity power-factor, the current in the right hand element is 30 degrees behind the voltage, and in the left hand element the current is 30 degrees ahead of the voltage, and the measurement is positive in both elements, so that the algebraic sum of the two measurements is the total power in the circuit. Also at the maximum theoretical angle of lag of 90 degrees, the current in the right hand element is 120 degrees behind the voltage and the measurement negative, while in the left hand element the current is 60 degrees behind the voltage and the measurement positive. The measurements in the two elements being equal, the resulting total measurement by the meter is zero. The measurement of reactive volt-amperes must be just the reverse, that is, for a balanced load at unity power-factor the total measurement must be zero and at the maximum theoretical angle of lag of 90 degrees, the measurement in reactive volt-amperes must be the same as the total power at unity power-factor when the meter was connected for measuring actual or true power.

In order to meet these conditions, the connections in Fig. 76 are arranged so that the voltage impressed on the right hand element of the wattmeter, represented on the vector diagram in Fig. 77 as E_R, is equal to $E_2 + 0.5\,E_1$ (vectorially). Since E_2 is equal to $1.15\,E_{2\,3}$ and lags behind E_R by the angle whose sine is 0.5, E_R is equal to $1.15\,E_{2\,3}\cos 30^\circ = E_{2\,3}$ or the nominal voltage on the secondary side of the voltage transformers. I_1, representing the current which flows through the right hand element, is 60 degrees ahead of E_R, and the measurement by this element W_R is $E_R\,I_1\cos 60^\circ$, or omitting the sub-figures, since E_R is equal to the line voltage and I_1 is the line current, $W_R = EI\cos 60^\circ =$

$0.5\ EI$. The voltage impressed on the left hand element is $0.5\ E_2 + E_1$ (vectorially) which is represented by E_L in the vector diagram. Since E_1 is equal to $1.15\ E_{1\ 2}$ and is 30 degrees ahead of E_L, E_L is equal to $1.15\ E_{1\ 2}\ cos\ 30° = E_{1\ 2}$ or the nominal voltage on the secondary side of the voltage transformers. I_3, representing the current which flows through the left hand element, is 120 degrees ahead of E_L and the measurement in this element W_L is $E_L\ I_3\ cos\ 120°$ or, omitting the sub-figures, $W_L = EI\ cos\ 120° = -\ EI\ sin\ 30° = -\ 0.5\ EI$. The total measurement by the meter (reactive volt-amperes) given by the algebraic sum of the measurements in the two elements is zero, which is correct for the balanced load at unity power-factor.

The wattmeter's measurement may be shown to correspond to the general expression for the reactive volt-amperes in a three-phase three-wire circuit, $EI\ sin\ \phi$, in the connection with the vector diagram in Fig. 78, which is for the condition of a balanced load at any power-factor where the current lags by an angle ϕ. The line currents are then $30° + \phi$ behind the line voltages. I_1, the current which flows through the right hand element of the wattmeter is $60° - \phi$ ahead of the voltage E_R, and the measurement in this element is $E_R\ I_1\ cos\ (60° - \phi)$ or, omitting the sub-figures, $W_R = EI\ cos\ (60° - \phi) = 0.5\ EI\ (cos\ \phi + 1.73\ sin\ \phi)$. I_3, the current which flows through the left hand element is $120° - \phi$ ahead of E_L and the measurement by this element is $E_L\ I_3\ cos\ (120° - \phi)$ or, omitting the sub-figures, $W_L = EI\ cos\ (120° - \phi) = -\ EI\ sin\ (30° - \phi) = 0.5\ EI\ (1.73\ sin\ \phi - cos\ \phi)$. The algebraic sum of the measurements in the two elements is $1.73\ EI\ sin\ \phi$.

In order to observe the wattmeter's action in measuring the reactive volt-amperes at different power-factors, both lagging and leading, the measurement will be determined from a vector analysis of the circuit at a number of different angles of lag and lead. In each case the results are to be compared with the reactive volt-amperes as calculated from the general expression $1.73\ EI\ sin\ \phi$.

In Fig. 79 a vector diagram is shown for a balanced load where the current lags 30 degrees. The line currents I_1, I_2 and I_3 are 60 degrees behind the line voltages $E_{1\ 2}$, $E_{2\ 3}$ and $E_{3\ 1}$ respectively. I_1 is 30 degrees ahead of E_R and the measurement in the right hand element is $E_R\ I_1\ cos\ 30°$ or, omitting the sub-figures, $W_R = EI\ cos\ 30° = 0.866\ EI$. I_3 is 90 degrees ahead of E_L and there is not any measurement in the left hand element. The reactive volt-amperes calculated from the expression $1.73\ EI\ sin\ \phi$ equal $0.866\ EI$ which is the same as the meter measures.

A vector diagram is shown in Fig. 80 for a balanced load where the current lags 60 degrees. The line currents are then 90 degrees behind the line voltages. I_1 is in phase with E_R and the measurement in the right hand element is $E_R\ I_1$ or, omitting the sub-figures, $W_R = EI$. I_3 is 60 degrees ahead of E_L and the measurement in the left hand element is $E_L\ I_3\ cos\ 60°$ or, omitting the sub-figures, $W_L = EI\ cos\ 60° = 0.5\ EI$. The sum of the measurements in the two elements is $EI + 0.5\ EI$. The reactive volt-amperes calculated from the expression $1.73\ EI\ sin\ \phi = 1.5\ EI$ which is the same as the meter measures.

A vector diagram is shown in Fig. 81 for a balanced load where the current lags by the theoretical maximum angle of 90 degrees. The line currents are 120 degrees behind the line voltages. I_1 is 30 degrees behind E_R and the measurement in the right hand element is $E_R\ I_1\ cos\ 30°$ or, omitting the sub-figures, $W_R = EI\ cos\ 30° = 0.866\ EI$. I_3 is 30 degrees ahead of E_L and the measurement in the left hand element is $E_L\ I_3\ cos\ 30°$ or, omitting the sub-figures, $W_L = EI\ cos\ 30° = 0.866\ EI$. The sum of the measurements in the two elements is $1.73\ EI$. The reactive volt-amperes calculated from the expression $1.73\ EI\ sin\ \phi = 1.73\ EI$ which is the same as the meter measures. For this case all the volt-amperes are reactive and there is no true power being delivered by the circuit.

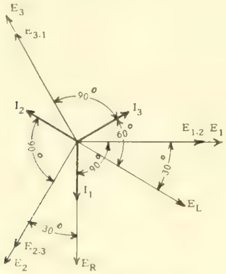


FIG. 80—BALANCED LOAD WITH CURRENT LAGGING 60 DEGREES

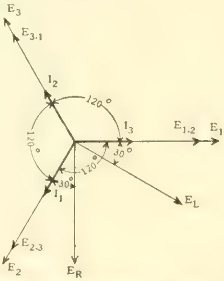


FIG. 81—BALANCED LOAD WITH CURRENT LAGGING 90 DEGREES

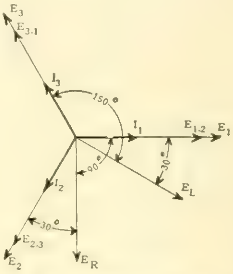


FIG. 82—BALANCED LOAD WITH CURRENT LEADING 30 DEGREES

A vector diagram is shown in Fig. 82 for a balanced load where the current leads 30 degrees. The line currents are in phase with the line voltages. I_1 is 90 degrees ahead of E_R and there is no measurement in the right hand element. I_3 is 150 degrees ahead of E_L and the measurement in the left hand element is $E_L\ I_3\ cos\ 150°$ or, omitting the sub-figures, $W_L = EI\ cos\ 150° = 0.5\ EI$. This is the same as the result with lagging current except that it is negative, that is, the deflection is in a negative direction.

In Fig. 83 is shown a vector diagram for a balanced load where the current leads 60 degrees. The line currents are then 30 degrees ahead of the line voltages. I_1 is 120 degrees ahead of E_R and the measurement in the right hand element is $E_R\, I_1 \cos 120°$ or, omitting the sub-figures, $W_R = EI \cos 120° = -0.5\, EI$. I_3 is 180 degrees from E_L and the measurement in the left hand element is $-E_L\, I_3$ or, omitting the sub-figures, $W_L = -EI$. This is again the same as the result with a lagging current, except it is negative.

Thus it is seen that the results with leading currents are the same as with lagging currents except that the deflection is in a negative direction. Therefore, a polyphase wattmeter, when used for measuring reactive volt-amperes in a circuit when the current may either lag or lead, should be provided with a zero-center scale, so that it may give full scale deflection in either direction. Then the meter indicates whether the current lags or leads by the deflection being in a positive or a negative direction. If the load on the circuit is always to have a lagging current, the connections in Fig. 76 are correct for a positive deflection and a standard scale is sufficient, or if the load is always to have a leading current, the connections to the voltage coils of both elements may be reversed and the meter's deflection will be in a positive direction for a leading current and a standard scale is again sufficient.

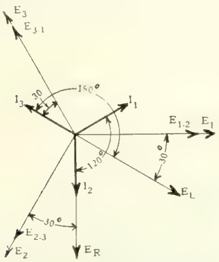


FIG. 83—BALANCED LOAD WITH CURRENT LEADING 60 DEGREES

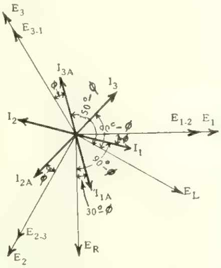


FIG. 84—SINGLE-PHASE LOADS AT ANY POWER-FACTOR

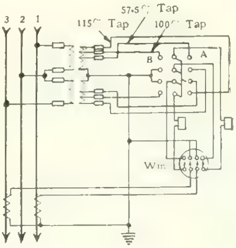


FIG. 85—CONNECTION FOR MEASURING EITHER TRUE POWER OF REACTIVE VOLT-AMPERES

It can be further shown that the polyphase wattmeter connected as in Fig. 76 correctly measures the reactive volt-amperes in the three-phase three-wire circuit for unbalanced loads by considering the extreme case of unbalancing where single-phase loads are connected between any two of the lines. A vector diagram for the three possible conditions is shown in Fig. 84. The voltages are the same as in vector diagrams shown in Figs. 77 to 83 inclusive. I_1 and I_2 represent the line currents when the single-phase load is between lines *1* and *2*. I_1 is shown lagging behind the line voltage $E_{1\,2}$ by an angle ϕ in order to cover any power-factor. Since there is a current transformer in line *1* and not in line *2*, the only measurement is in the right hand element of the meter. The current I_1 which flows through the right hand element is $90° - \phi$ ahead of E_R and the measurement in this element is $E_R\, I_1 \cos (90° - \phi)$ or, omitting the sub-figures, $W_R = EI \cos (90° - \phi) = EI \sin \phi$ which is correct for the reactive volt-amperes in the single-phase circuit. I_{2A} and I_3 represent the line currents when the single-phase load is between lines *2* and *3*. The current I_{2A} is shown lagging by an angle ϕ to represent any condition of power-factor. In this case the only measurement is in the left hand element, because there is a current transformer in line *3* and not in line *2*. The current I_3 which flows through the left hand element is $90° - \phi$ ahead of E_L and the measurement in this element is $E_L\, I_3 \cos (90° - \phi)$ or, omitting the sub-figures, $W_L = EI \cos (90° - \phi) = EI \sin \phi$ which is again correct for the single-phase circuit. I_{3A} and I_{1A} represent the line currents when the single-phase load is between lines *3* and *1*. I_{3A} is shown lagging by an angle ϕ in order to be representative for any power-factor. As there is a current transformer in each line, there is a measurement in both elements of the meter. In the right hand element I_{1A} is $30° - \phi$ ahead of E_R and the measurement is $E_R\, I_{1A} \cos (30° - \phi)$ or, omitting the sub-figures, $W_R = EI \cos (30° - \phi) = 0.5\, EI\, (1.73 \cos \phi + \sin \phi)$. In the left hand element I_{3A} is $150° - \phi$ ahead of E_L and the measurement is $E_L\, I_{3A} \cos (150° - \phi)$ or, omitting the sub-figures, $W_L = EI \cos (150° - \phi) = -EI \sin (60° - \phi) = 0.5\, EI\, (\sin \phi - 1.73 \cos \phi)$. The algebraic sum of the measurements in the two elements is $EI \sin \phi$ which is also correct for the single-phase circuit. A similar line of reasoning will show that the results in case of unbalanced loads where the current leads are the same as when the current lags, except that the deflection will be in a negative direction.

It is sometimes desired to use the same polyphase wattmeter for measuring either the reactive volt-amperes or the true power in a three-phase three-wire circuit. This can be done with the apparatus and corrections shown in Fig. 85. The voltage transformers are the same as those used in Fig. 76, except that they must be provided with a nominal voltage (*100%*) tap. If the four-pole, double throw switch is thrown to position *A*, the voltage coils are connected to the voltage transformers in exactly the same manner as in Fig. 76 and the meter will measure the reactive volt-amperes. If the switch is thrown to position *B*, the voltage coil in the right hand element is connected to the nominal secondary voltage corresponding to the line voltage from line *1* to line *2*, and the voltage coil in the left hand element is connected to the nominal secondary voltage corresponding to the line voltage from line *3* to line *2*, which is correct for measuring the true power in the circuit. The connections from the current transformers to the current coils of the meter are the same for measuring either reactive volt-amperes or true power. A meter used in this way should have a zero-center scale to provide for indicating the reactive volt-amperes with either leading or lagging currents, as was explained in connection with Fig. 76. When measuring true power the meter will show a positive deflection so long as power is transmitted in a positive direction as indicated by the arrow points on the line leads.

Main Driving Motors

For the Chicago, Milwaukee & St. Paul Passenger Locomotives

[illegible]

THE MAIN driving motors on the new 275 ton, 3000 volt passenger locomotives for the Chicago, Milwaukee & St. Paul Railroad are of the twin armature geared type. This type of motor permits the development of greater horse-power per axle than any other type in which a single motor mounted between wheel flanges drives a single axle. By means of this design it was possible to make each motor of sufficient capacity to require only six driving axles per locomotive. The motors are insulated for operating two in series on a 3000 volt trolley line, giving 1500 volts per motor, or 750 volts across each of the twin armatures, which are connected permanently in series. The general appearance of this type of motor is shown in Figs. 1 and 2. The ratings of the motor with full field, according to A. I. E. E. Standardization Rules are given in Table I.

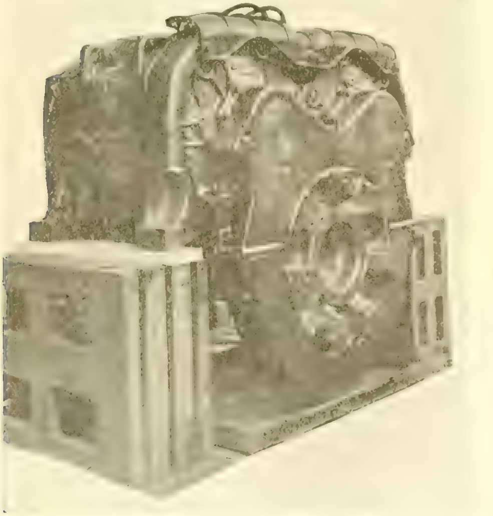


FIG. 1—TWIN MOTOR FOR THE CHICAGO, MILWAUKEE & ST. PAUL LOCOMOTIVES

Assembled complete with quill and gear covers

By using geared motors, high efficiency is obtained, especially when operating at the peak load on the heavier grades. Moderate locomotive speeds (consistent with the schedule) and high motor efficiency on the heaviest sustained grades are both desirable, due to the fact that the energy supply is obtained from water power in which the principal item of cost is that due to investment and hence peak loads should be kept as low as possible.

The maximum sustained compensated grades on the electrified sections of the Chicago, Milwaukee & St. Paul Railroad are 2 to 2.2 percent, which requires 325 to 370 amperes per motor operating on full field with a normal 950 ton train. With a 10 percent drop in line voltage the speed on these grades is approximately 22 miles per hour.

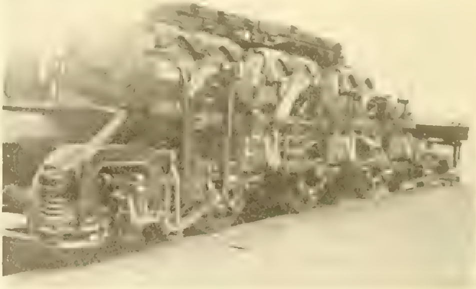


FIG. 2—THREE TWIN MOTORS ASSEMBLED ON TRUCK

The performance curves of these motors are given in Fig. 3. The maximum efficiency on full field of slightly over 90 percent is obtained between 250 and 450 amperes. The efficiency as shown by this curve is based on input and output tests, and does not include the losses in the blower motors, which do not need to be used under ordinary conditions. As was anticipated, the loss in the gears and quill bearings indicated by these tests is much less than that assumed by the A. I. E. E. rules, which were based on tests made on a much smaller motor.

In obtaining these tests the quill drives of two motors were coupled together as shown in Fig. 4 in such a way as to include all the normal gear losses. The motors were loaded on one another as shown in Fig. 5, the full voltage being maintained across the motors by plant *A* which supplies the friction, windage and iron losses. Full-load current is circulated through the motors by the booster *B*, which supplies the copper loss. The armatures, commutating fields and main field of the motor and the main field of the generator carry the normal full-load current. The armatures and commutating fields of the generator carry slightly less current, the difference being supplied to the motor by plant *A*.

TABLE I—MOTOR RATINGS WITH FULL FIELD

	Out-put Horse-Power	Tractive Effort Pounds	Speed Miles Per Hour
One hour	700	11 000	23.8
Continuous, with forced ventilation	507	8100	26
Continuous with natural ventilation	400	5000	30

The booster carries the same current as the generator, and supplies voltage sufficient to overcome all the *RI* drops. The generated e.m.f. of both the motor and the generator is the same, since the fields and speeds are the same, and hence the core losses and friction and windage losses are practically the same. The gear and axle bearing losses of the motor and generator are also practically the same. This scheme of testing gives all the losses in the two machines, which can be easily segregated and properly divided between motor and generator. Since all the losses can be measured directly this method gives very reliable test results.

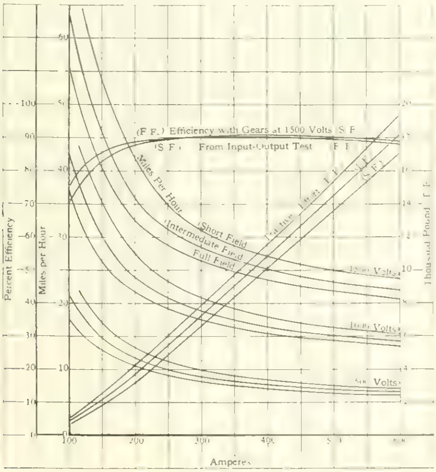


FIG. 3—MOTOR CHARACTERISTIC CURVES

When the external blowers are not running, high continuous capacity is obtained by a draft of air drawn through the motors by fans on the pinion end of each armature, as shown in Fig. 6. Air enters the motor through an inlet on top, which is on the center line of the truck when the motors are mounted. It passes through a short passage to the commutator end of the motor and then down into the interior, passing back toward the pinion end in parallel paths through the armature coils, air-gaps and spaces between the field coils to the fans at the rear, from which it is thrown out through circumferential openings in the pinion end of the frame. These openings are protected from snow and water by adequate covers. The natural ventilation is so good that, when starting cold, the motors can operate without the external blowers for two hours at their rated continuous load with forced ventilation; and they will operate continuously without the external blowers at 70 percent of this load, so that the blowers will not be required except for short periods on the heavier grades.

FIG. 4—MOTORS ASSEMBLED FOR LOADING BACK TEST

The use of twin armature motors makes it possible to limit the maximum voltage per armature to 750 volts, giving 1500 volts per motor, with at least two motors always connected in series on the 3000 volt line. The commutating and flashing characteristics of the 750 volt armatures are inherently good. As shown in Fig. 6 the armature is of the standard railway motor type. The armature spider and pinion end bell are made in a single casting, into which the forged steel shaft is pressed, so that it can be removed for replacement without disturbing the armature windings. The armature core is balanced before the commutator or fan is applied. The fan and commutator are balanced independently before being applied to the core. There are 205 commutator bars on each armature giving a low voltage between

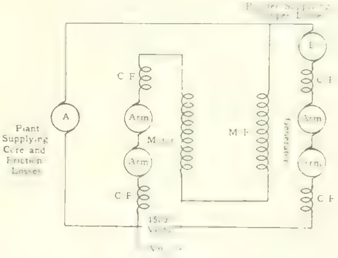


FIG. 5—DIAGRAM OF TEST CONNECTIONS

bars. The thickness of the mica between bars is 0.04 inches.

There are four main and four commutating field poles and coils per armature, the coils being wound from copper strap insulated between turns with asbestos. The commutating coils are insulated for line voltage, but the main coils are always on the ground side and are insulated for only one-half line voltage. The insulation around the field coils is of mica with a protective covering of heavy cotton tape. All the coils are vacuum impregnated with a heat conducting and water proof compound.

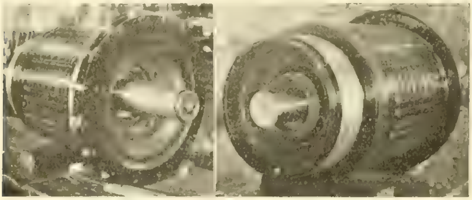


FIG. 6—PINION END AND COMMUTATOR END OF ARMATURE

The air-gap of the motor is proportioned to give a steep speed curve so that it is necessary to shunt only one-third of the main field turns to obtain the maximum speed desired with a full tonnage train on a level track. The inductive shunts used in shunting the fields are designed to keep the proper proportion of the current in the fields under conditions of varying current due to fluctuating line voltage. By using a laminated iron core with an air-gap, the size of the shunts is kept down, and at the same time their inductive characteristics are made to correspond to the field coils, the inductance of which is reduced due to eddy currents in the solid frame during rapid changes of current.

FIG. 7—COMMUTATOR END OF MAIN MOTORS

In addition to the advantage of low voltage per armature which is obtained by using the twin armature motors, other desirable features are also gained. These can best be understood by comparing the twin armature motor with a single armature motor of twice the armature diameter, running at one-half the speed and having twice the number of poles. With such a motor two gears would be used, and every inch added to the total gear face would have to come off the armature core length. To compensate for this reduction in length, a large diameter would have to be used, greatly increasing the weight. Even with only double the diameter, such a motor would occupy so much vertical space that it would raise the cab deck and allow less room for apparatus in the cab, so that the single larger motor would result in a longer and heavier cab. While the weight of the active material in the motor would be approximately the same, since it varies approximately as the diameter, the weight of the inactive material would be much greater, since it varies approximately with the square of the diameter, hence the weight of a single armature motor would be greater. The inertia effect on the quill springs of the single armature motor would be greater, both because of the relatively greater weight, and because the radius of gyration would be relatively greater, since the bulk of the weight of the armature is near the surface. The single armature motor, being wound for 1500 volts, would have twice as many commutator bars between brushholders. As the brushholders would be the same distance apart as on the twin armature motor, the commutation bars on the single armature would be much thinner thereby increasing the tendency to flash. Furthermore the single armature motor would require a multiple winding, with cross connections, and it would hence be necessary to keep the air-gaps nearly uniform under all the poles. The multiple winding would require a two-turn armature coil, which would be less substantial than the single turn open coil of the two circuit winding.

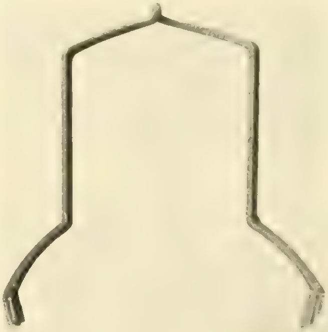


FIG. 8—ARMATURE COIL

From the above it can be seen that the twin armature motor has many advantages over the single armature motor. The savings in weight and cab space alone are sufficient to justify it. From the longitudinal section shown in Fig. 9 it can be seen that the length of core would be reduced if the total gear face were increased, which is obviated by the use of two pinions on the twin armature motor.

The armature coil used in the twin armature motor is shown in Fig. 8. It consists of five single coils, each having a single turn of two straps in parallel and the complete coil is entirely insulated with mica, with a final taping of strong cotton tape, before being applied to the armature core. After being wound, the armature is dipped in insulating varnish and baked several times. The armature diameter is 26 inches and the length of the core is 13.5 inches while the gear face is six inches. The weight of the motor complete with gear, pinions, gear case, bearings, quills and details is 25,400 pounds, giving a remarkably low weight per horse-power.

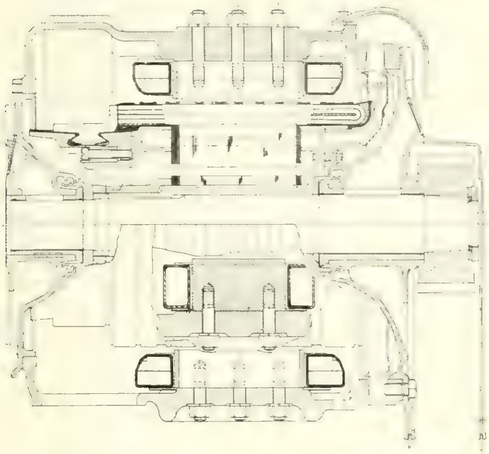


FIG. 9—LONGITUDINAL SECTION THROUGH MAIN MOTOR

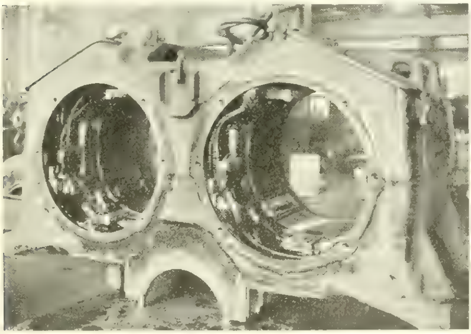


FIG. 10—MAIN MOTOR FRAME
Showing brushholders and field coils.

There are four brushholders per armature, each carrying three ⅝ by 1¾ inch carbons. As shown in Fig. 10 the brushholders support consists of a block into which are pressed insulating pins, onto which the insulation is moulded and machined to exact size. The portion of the insulating pin extending beyond the block is surrounded by a porcelain bushing, which gives a long creeping surface to ground. The accessibility of motor parts, such as brushholders and bearings is good. It is possible to inspect and remove carbons from six of the brushholders per motor from the cab. The other two brushholders can be inspected from beneath, without, however, the necessity of using a pit. The spring support of the motors eliminates the direct shocks which are received from the rail, and the location above the axles permits better protection of the motors from snow, water, dirt and roadbed obstructions.

One of the special features of the motor is the substantial steel frame, made in one solid casting, and the large and substantial bearings. The pinion end armature bearings are 6.25 by 11.25 inches and the commutating end armature bearings are 5.25 by 7.75 inches. The quill bearings are 15 inches in diameter by 12 inches long. The gear ratio is 24 by 89 with 1.75 diametral pitch. The gear face is 6 inches and the clearance under the gear case with 68 inch wheels is 6⅞ inches. The upper and lower parts of the gear case are shown in Fig. 11.

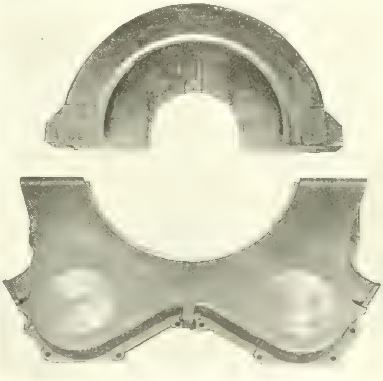


FIG. 11—GEAR CASE

These locomotive motors are of large capacity for their weight and size. They are efficient, have good electrical characteristics, are economical in weight and very rugged in construction. Their performance in actual service has been very creditable.

The Protection of Iron from Corrosion

Leon McCulloch

If MEANS were not taken for protecting iron from rust and corrosion under most conditions of service, this metal could not long endure, for the action of air and water would cause it to return to its original oxide state. An enormous amount of research has been done to discover ways of treating or alloying iron to make it more resistant to corrosive agents, and also to devise suitable methods of protecting it with coatings. The conclusion has been reached that the purer iron is made, the better does it resist atmospheric corrosion. Electrolytic iron, ingot iron and wrought iron are more resistant than iron higher in carbon. Recent experiments[1] indicate that the resistance of wrought iron is due to its purity, and not to its included oxide or slag, as was formerly supposed. Gases occluded in steel[2] are believed to render it more easily corroded. On the other hand, the addition of a small percent of copper to steel[3] has resulted in an increased resistance. Although there is a difference in the ease with which the commercial forms of iron and steel corrode in the atmosphere, none of them are resistant enough to be used without protective coatings.

THE LESS CORROSIVE IRON ALLOYS

There are, however, alloys of iron which are more non-corrosive than iron itself and which have fields of usefulness, limited by their resistance to corrosive agents, by their physical properties and by their cost. Certain elements which, when present in small quantities, accelerate corrosion, in larger percentages, form non-corrosive alloys. Among these are carbon and silicon.

Carbon steel is more easily corroded than pure iron, yet cast iron lasts for years where pure iron would be destroyed. It is particularly useful for service underground. It is also used for containers for strong acids.

A small amount of silicon causes steel to corrode very rapidly, yet high silicon iron is practically acid-proof, and is being very widely used for equipment in chemical plants. It has the disadvantage of being quite brittle and so hard that it cannot be machined, but fittings are made by grinding.

Alloys of iron and chromium are peculiarly resistant. The 14 percent alloy known as "stainless steel" remains bright indefinitely under severe exposure, and is attacked only by strong acids and by electrolysis.

The nickel and manganese steels not only have excellent mechanical properties but also resist corrosion. It is said that in general those alloys in which iron is present in the austenitic or non-magnetic state are unusually resistant.

Since the less corrosive alloys cannot be generally used, protection must usually be secured by means of coatings. These may, for convenience, be divided into classes, of which the first to be considered are the metallic coatings.

METALLIC COATINGS

Zinc, of all the metals, has been most generally and successfully used for the outdoor protection of iron. Tin is the only metal which has rivalled it. Zinc is easily soluble, even in weak acids, while tin is almost insoluble. Tin is consequently used for coating household utensils and containers for food. Zinc is very resistant to exposure in the atmosphere. Sheet zinc is an excellent roofing material. It protects itself against corrosion by forming insoluble zinc compounds upon its surface. When used as a coating for iron, zinc not only protects itself, but also by electrolytic action prevents exposed iron from going into solution; and deposits the insoluble zinc compounds also over the surface of the iron. In this way the breaks in a zinc coating heal themselves, while breaks in a coating of tin cause rapid pitting and destruction of the iron beneath. Tinning is valuable as a protection for sheet iron during storage and is an aid in soldering, but for outdoor use tinned iron must be painted. Tinned household utensils are usually heavily coated, but these must be kept dry when not in use or they soon rust through. Tin cans, although given a very thin coating only, do not rust on the inside after sealing because the air is excluded.

Although zinc coatings are very resistant under ordinary atmospheric exposure, there are conditions under which they are rapidly destroyed. Thus they do not resist waters containing acids, acid fumes or ammonia; they are rapidly destroyed by hot water in presence of air; their life is apt to be short when buried in the soil.

There are three practical methods of applying zinc to iron:—by hot galvanizing, by Sherardizing and by electrogalvanizing.

The hot galvanized coating is made by dipping the iron into molten zinc in an iron tank. Upon the surface of the iron an alloy of iron and zinc forms, which is high-melting, hard and brittle. To this, on removal from the bath, a thin film of melted zinc adheres and crystallizes on cooling into the familiar spangles of galvanized iron. When wire is galvanized, the excess melted zinc is removed by wiping through sand. On sheets and other articles the excess is usually allowed to drain away. The thickness of the coating depends upon the temperature of the zinc, the time of immersion, the size and nature of the iron, etc. The thickness of coatings thus varies greatly from time to time and on different materials.

Hot galvanizing is probably the most expensive of the three methods of applying zinc. It is not economical where there is work to be treated only occasionally, since the bath must be kept hot continually. Several days are required to heat up a large galvanizing kettle without overheating its iron bottom and forming holes by the solvent action of the zinc.

The hot galvanizing method is best suited for treating telegraph and fence wire, cables, sheet iron, tanks, pipes, large, heavy and rough objects. It is not suited for coating screws and nuts, because the threads would be filled up and require re-threading. These, and other small and irregular-shaped articles, where there are close-fitting parts, and a smooth finish and neat appearance are desired, should either be Sherardized or electrogalvanized. Sherardizing is perhaps the cheaper of the two. It has a great advantage over the hot galvanizing process, where the work comes through in intermittent lots, in that the drums or furnaces need be heated only while the treating is being done. In the Sherardizing process interior and exterior parts are coated equally well. Pipes may be coated inside as well as out. It is thus particularly suited for objects of irregular shape.

The electrogalvanizing method is best suited for objects without deep recesses and for production in large quantities by automatic machines or in drums. This method must be used for very delicate parts which would be injured by tumbling, and for steel which would be injured by the Sherardizing temperature. The electrically-deposited coating is superior for parts which must make electrical contact, such as carbon brush-holders and other electrical devices.

In the Sherardizing process, the iron to be coated is placed in a drum with impure zinc dust, rotated slowly and heated at a temperature below the melting point of zinc. A trace of the zinc vaporizes, and saturates the atmosphere of the drum with zinc vapor. This vapor then combines with the iron to form a layer of zinc-iron alloy upon the iron surfaces, and more zinc vaporizes to take its place in the atmosphere. The coating of zinc-iron alloy is hard and brittle and continues to grow in thickness, forming as the scale does upon red-hot iron. There is an increase in dimension for which allowance must be made. Zinc does not penetrate the iron, and there is no layer of pure zinc formed at the surface. Coatings deposited by the electrolytic method, on the other hand, consist wholly of zinc which is practically pure.

The general opinion is that of the three coatings, the hot-galvanized, Sherardized or electrogalvanized, for a given weight of zinc, the protection afforded by the three is about equal. The quality of all these coatings on the market varies greatly, depending on the care exercised in the processes. With Sherardizing especially careful standardization and control is necesssary. The composition of the zinc dust and the temperature should be accurately regulated.

The most reliable method for determining the quality of a zinc coating is to measure the weight of zinc upon a unit area. This weight should not be less than 0.1— 0.2 gram per square inch. It may be determined by weighing a piece of measured area and finding its loss in weight when the coating is removed in a solution which dissolves zinc but not iron. Such a solution is the following:

Ammonium chloride—30 grams
Saturated ammonia—160 c. c.
Water—300 c. c.

A metal which would closely rival zinc as a protective coating in many kinds of service, if it could be cheaply applied, is lead, since on account of its low cost, heavy coatings could be used. The electroplating of lead is attended with difficulties. Iron is not readily coated with it by dipping, since lead does not alloy with iron. In the manufacture of terne-plate, tin is added to the lead to cause adherence to iron. By a recently developed process[4], iron has been coated with lead by the use of a flux of antimony chloride. Shingles and fence wire treated in this way have given service equal to galvanizing and were cheaper. Heavily lead-coated iron should give excellent protection against acids and corrosive vapors. It does not withstand acetic and other organic acids, for they are agents in its conversion into basic lead carbonate or white lead.

Copper is little used as a coating for iron except on work that is to be nickel-plated. Copper plating is used occasionally for decorative purposes, to match the color of copper parts, or to give iron the appearance of a better material. Steel wire is sometimes given a polished copper finish to prevent rusting in storage. Copper-clad steel has been used for telegraph wire, but has not come into general use. This steel has been made by drawing down an ingot of iron embedded in copper, and also by electroplating. Copper coatings are usually finished by polishing, and are lacquered to prevent tarnishing and rusting of the iron. Electrolytic coatings are usually porous and offer little protection against moisture.

Iron may be plated with brass from a solution of copper and zinc cyanides. Care is required to maintain uniform color of the deposit.

The uses of nickel plating on iron are numerous, but nickel coatings are of little protective value when the conditions are severe. These coatings are always porous, and rusting of the iron causes first discoloration and then ultimately the destruction of the coating. Nickel plating is used upon stoves and electric heaters where the temperature is somewhat high. Nickel is not ideal for this use since it readily darkens in color. Cobalt is similar in appearance to nickel when plated, and is more easily deposited electrolytically. It tarnishes, however, and discolors more readily than does nickel.

Chromium may with care be deposited upon iron[5]. It should be a superior substitute for nickel for use at high temperatures, if a practical process of plating can be evolved, since it does not darken in color as does nickel when heated.

Aluminum cannot be deposited successfully from aqueous solutions. Coatings of an aluminum-iron alloy are formed by calorizing, a process similar to Sherardizing. This coating is used to protect iron from oxidation at temperatures above red heat.

VITREOUS ENAMELS

Besides the metallic coatings, there are others equally important. Among these are the vitreous enamels. These are not only used for household utensils and sanitary fixtures, but also for a variety of purposes such as for table tops, signs, stoves, and for acid-resisting linings for large tanks and other apparatus used by chemical manufacturers. The materials for these enamels are ground with water and applied as a thin slip to the iron to be coated. After drying, the iron is heated in a muffle furnace to a red heat, causing the enamel to melt and flow smoothly. The vitreous enamels have not been extensively used in electrical manufacture, for the process is an expensive one, requiring special equipment, and much skill is required to carry it on successfully. These enamels have the disadvantage that they crack under large temperature changes. Were it not for this, they might be used as a substitute for nickel plating where the temperature is high.

CHEMICALLY-FORMED COATINGS

The coatings formed on iron by chemical action with its surface will be next considered. Such are the Costlett, or Parker, and the various oxide coatings. The use of oil is necessary to render this type of coating really rust-resisting, for the coatings themselves are porous and have little value as rust-preventives. This type of coating does not stand long exposure to the weather, but is useful where moderate protection is required and a thin, attractive finish is desired.

The Costlett coating, on which the Parker is an improvement, is the most resistant coating of this class. The iron is immersed for a few hours in a dilute acid solution of ferrous and ferric phosphates, and receives a deposit of insoluble iron phosphates. After drying this is greenish in color, but when oiled it forms a dead black coating which is thin and durable. It may be applied to very fine and delicate parts.

Another method of producing a fine dead-black finish on iron was patented recently by Sestini and Rondelli, and a similar process several years ago by Hollis. The iron is given a coating of magnetic oxide by electrolyzing in a caustic soda solution at a high temperature, after which it is washed, dried and oiled. This finish is not so resistant to rusting as the Parker coating, but its appearance is very attractive.

An older method of securing a dead-black finish is the Bower-Barff, of which several modifications have been patented. The iron was heated to redness in a chamber into which steam and reducing gases were passed to form magnetic oxide. The coating was oiled to make it really rust-resisting.

When iron, having a clean surface is heated in air, a coating of oxide forms and assumes in succession various colors, called "temper colors". These oxides render the iron somewhat resistant to rusting, but they must usually be oiled, lacquered, or varnished. By this means, attractive finishes are applied to small articles, such as instrument parts, watch springs and hands, tools, parts of guns, screws, etc. To obtain uniform results with these colors the metal surfaces must be clean and the heating carefully controlled.

"Russian" sheet iron, of which stoves and similar articles are made, is protected with a glossy blue-black oxide coating. This iron does not rust readily in storage and retains its attractive appearance when heated. Most commercial sheet and structural iron is protected more or less from rusting by coatings of oxide or mill scale.

PAINTS AND SIMILAR COATINGS

The most widely used and best known method of protecting iron is by the use of paints and similar materials. These organic coatings have the advantage over those of metallic nature in that they are readily applied, and usually make a better appearance. They must, however, for outdoor use, be free from holes or breaks. Hence they are not suitable for coating materials of iron which must withstand handling, since their soft, weak surfaces would be injured thereby. There are two reasons for using paints—to protect and to decorate. We are concerned here mainly with the protection of iron for service out-of-doors, indoors or against corrosive chemicals. For service indoors, any oil, paint or varnish that will give a continuous and adherent covering affords ample protection. Considerations such as usage, apearance, ease of application and cost guide in the selection of coatings of this class. Where resistance to chemicals is also required, such as acid or alkaline fumes or drippings, the paint must be selected which will be durable under the given conditions. For this service, the asphalt and coal tar paints are the most resistant. These materials are not especially permanent in service out-of-doors, for they harden and become weak and brittle when exposed to heat, air and sunlight. Varnishes or japans made by mixing asphalts with oil varnish are quite serviceable and are widely used for painting iron poles, fences and parts of machinery.

The varnish or japan finishes may be either air dried or baked. In general the coatings obtained by baking are superior not only in hardness and toughness, but in endurance under exposure. The use of baking is resorted to in factories to speed production and save space that would be required for the slower drying at room temperature.

Paints may be applied either by brushing, spraying, or dipping. Brushing is economical in material but costly in labor. For spraying, the cost of labor is low, but much paint is wasted. Dipping is saving both of labor and material.

The best outdoor paints for iron are probably those composed of oils and pigments suitably combined to form durable, elastic films which adhere with cement-like firmness to the surface. The typical and most widely-known paint of this kind is the mixture of red lead and linseed oil used as a priming coat on structural iron. Paint pigments have been separated into groups, according as they accelerate or inhibit rusting, or are neutral, when they are placed in water in contact with iron. The use of inhibitive or neutral pigments only is recommended. It would appear, however, that of more importance is the permanence and adherence of the film formed by the union of the pigment with the oil.

All paint films are more or less permeable to both water and oxygen. But by their close adherence to the iron they prevent rusting. If, however, the surface to be painted is rusted, a good adherence of paint and iron is not obtained, and rusting may proceed even under the paint; for the presence of rust causes rusting to continue. The following explanation will make clear the reason for this:—

Suppose an iron surface is in water containing oxygen and salt in solution. For various reasons there are slight potential differences over the surface, which cause electric currents to flow from certain parts to other parts. As a result of this electrolysis, this reaction takes place:—

$$Fe + 2\,NaCl + 2H_2O = FeCl_2 + 2\,NaOH + H_2$$

The $NaOH$ formed may be washed away by the water. The ferrous chloride is oxidized to form ferric chloride and iron hydroxide or rust, which adheres to the surface and holds there the ferric chloride. This takes iron into solution to form ferrous chloride again. These reactions repeat themselves indefinitely. Ferric chloride held by the rust is very hygroscopic, retains water and causes rusting to continue. The result is a pitting of the iron and an accumulation of rust.

For these reasons rust upon iron acts to promote further rusting, and should be removed before applying protective paints. For rust prevents the close adherence of paint to iron, and rusting is permitted to continue by the slow diffusion of water and oxygen through the paint film. The removal of rust is best done mechanically, as by wire-brushing or sandblasting. The use of acids should be avoided, since iron salts left in the pores of the metal are only with difficulty removed and may cause rusting underneath the paint.

PIPES AND BOILERS

There are places where iron must be used without any protective coating, since there is no practical coating which is sufficiently durable. Such are the interiors of water and steam pipes, heaters, boilers and condensers. Corrosion in such cases may be minimized by the removal of oxygen from the water and the neutralization of acids. Oxygen may be removed from water by heating to near the boiling temperature. It may also be removed by passing the water through a tank containing expanded sheet metal stacked closely together to expose a large surface of iron to the water. Steam heating systems should be kept free of air or rapid corrosion will occur.

Attempts have been made to protect boilers and condensers electrolytically by immersing plates of zinc in electrical contact with the iron. This method of protection is only partially successful, for much of the iron surface is too far removed from the zinc to be under its protection. The same weakness is inherent in the Cumberland electrolytic method[6], used on British ships for the protection of condensers, in which current is passed from immersed iron plates to the surfaces to be protected.

Iron underground or embedded in concrete may be subject to rapid corrosion by electrolysis from stray currents. Work done on electrolysis by the Bureau of Standards[7] shows that to determine the danger of electrolysis it is essential to know, not simply the voltage drop, but the current that flows from the iron to the earth. For the soil resistance varies so largely that a measurement of voltage does not indicate necessarily the extent of the electrolysis. The really effective means of preventing electrolysis is by proper construction of electrical circuits. Temporary or partial relief may be had by use of pipe coverings, insulated joints, and pipe drainage.

PROTECTION DURING MANUFACTURE AND STORAGE

In conclusion some of the means used temporarily to protect iron from rusting during process of manufacture, storage and shipment will be mentioned.

Iron that has been cleaned with acids will rust on exposure to the air, unless a protective coating is applied. Rusting may be prevented until it is convenient to apply the coating by immersing the iron in still water. Running water contains oxygen and causes rusting. Better protection is afforded by immersion in lime water or caustic soda. The alkali precipitates the iron salts in the pores of the metal and makes it possible to dry without the formation of rust. In an alkaline solution of sodium dichromate bright steel is preserved indefinitely.

Clean iron soon rusts in storage. This may be prevented by washing the surface with dilute phosphoric acid and drying. The metal may then be stored without rusting until a finish is applied. It is not necessary to remove the phosphates before painting.

Tools and parts of machines must be protected during storage and shipment. Vaseline is commonly used for this. Soft asphaltic varnishes which are easily removed with solvents may be used for heavy machinery and afford excellent protection. A solution of tallow in turpentine gives a very good rust-proof coating to small iron parts.

Articles for household use, when soft grease would be objectionable, may be coated with beeswax or paraffin. On heating the apparatus, these cause little smoke or blackening when heated for the first time.

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Allowable Working Stresses in High-Voltage Electric Cables

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SEVERAL articles published during the past three years have maintained that the limiting feature in the operation of high voltage cables is the maximum voltage stress; and furthermore that if this maximum stress exceeds a value of about 19.5 kilovolts per centimeter in commercial cable as made today, the cable will fail in a relatively short time.*

It is of the utmost importance to cable users and manufacturers alike to know whether or not such limitations exist; and it is the purpose of this paper to throw light upon the subject from other data. The authors wish to express their admiration for the general excellence of the articles they propose discussing; and it is hoped that no criticism here offered will be construed as intended to detract from their value.

The position referred to briefly above is based on the fact that commercial insulation as at present manufactured contains air or gas bubbles, and these bubbles break down (so it is stated) whenever the stress in the solid insulation surrounding the bubbles exceeds about 21 or 22 kv per cm. The breakdown of these air bubbles is accompanied by the phenomenon of ionization, or internal corona, and the effect of this ionization, either due to heating or chemical action, is so to shorten the life of the cable that it will fail, so it is stated, within a period of from six months to six years, if it is operated above this stress. (See Appendix A).

A reasonable interpretation of the theory presented in these earlier papers is that the lower time limit of six months applies to cables operated well above the ionization stress, and thus with ionization present in large degree; and the higher time limit of six years to cables operated only slightly above ionization stress and thus with ionization present in relatively small degree.

Possibly the best method to check the correctness of these conclusions is to consider cables in operation. This method of approaching the problem involves, first a method of determining accurately the location and value of maximum stress in a three-conductor cable when operated under three-phase pressure. Second, an extensive statistical record of three-conductor cable installations, which must be sufficient to allow the calculation of the stresses, and to tell how long the cables have been in service. Such records are available and we are now able to calculate the stresses in three-conductor cables operating under three-phase voltage.

The maximum voltage drop per unit thickness in single conductor cables occurs at the surface of the conductor; and the value of this stress may easily be calculated. There does not seem to be any easily applied analytical method of determining the location of the point of maximum stress in three-conductor cables and the value of such maximum stress. (See Appendix B). It occurred to the writers that an experimental method could be made to yield the desired results and in 1913, they were able to show from experiments that for such distribution of insulation as is ordinary in three-core cables, the maximum stress under three-phase voltage occurs at the surface of the conductor and at that point on the conductor surface which is nearest the axis of the cable. It remained for Mr. R. W. Atkinson to refine these methods of experimentation*, and simplify the methods of determining these stresses over a wide range of insulating thicknesses and conductor sizes. His refined method consists in calculating the stress of an equivalent single-conductor cable, whose conductor is of the same size as that of the triplex cable, and whose insulation thickness is equal to the distance between the conductor surface and the center of the cable. A final correction factor must then be applied, depending upon the relative dimensions of the triplex cable. In calculating stress, we have made no allowance for the curvature of the fine wires composing the strand. The stresses were calculated as if the cable was composed of smooth round conductors of the same diameter as that of the stranded conductor. If any allowance was made for the stress due to stranding, the stresses shown in the tables would have been slightly higher, and therefore the figures shown are somewhat conservative. All calculations are expressed in terms of the effective value of a sine wave.

Applying the results of the experimental method of determining stress, the maximum stress corresponding to the operating voltage has been calculated in a

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*Clark & Shanklin, *Proc. of A. I. E. E.*, June 1917. Shanklin & Matson, *Proc. of A. I. E. E.*, February 1919. Clark & Shanklin, *Proc. A. I. E. E.*, June 1919.

*The methods and results are shown by Mr. Atkinson in his paper, *A. I. E. E.*, June 1919, only a portion of which is confined to the determinatioin of stresses in three-conductor cables under three-phase voltages.

large number of existing cables. It was found that a great many cables have operated at higher stresses than 19.5 kv for longer periods of time than six years. A number of these cables (taken from a list that now covers about 200 different installations) with the important data relating thereto are described in Table I. From the data given, it appears that these cables have not failed from ionization at these high stresses as predicted, for one or more of the following reasons:—

> *a*—No ionization was present, due to the fact that these cables are substantially different from those described and tested by the authors of the earlier papers, in that their insulations do not have air bubbles in them sufficiently thick to break down at stresses as low as 19.5 kv per cm.; or,
>
> *b*—If ionization was present at any time in these cables, that its effect was not so harmful as was predicted; or,
>
> *c*—That an ageing effect rapidly raises the stress, at which ionization begins, far above such low values as 19.5 kv per cm.

It is possible also that failure in any such short time as referred to above requires not merely that ionization should be present, but that it should exist in such degree that the energy represented by the concentration at a given point shall be of very considerable amount.

Cables are described in Table I which have operated at stresses above 19.5 kv per cm for periods of time of five years or longer. In most cases it is known that up to June, 1920, these cables had operated for the period stated at the given stress, although it has not been possible to learn as much in all cases, especially as regards the foreign cables.

Among the most interesting cables in the list are the 30 000 volt, triplex paper cables of the Berlin Electrical Works. It is understood that these cables have operated successfully for nine years with a maximum stress of 34.4 kv per cm. Others are the paper cables of the St. Paul Gas Light Company operating at 32 kv per cm. for 20 years, and still in operation. Noteworthy also is the cable of the Montreal Light, Heat & Power Company which has operated for 18 years, although the maximum stress here is but 23.5 kv per cm. Possibly the most interesting cables are the single conductor cables of the Prussian-Hessian State Railways. The maximum stress in one of these cables is 42.0 kv per cm. Information has been received that they both operated to the end of 1917 when they were removed for war reasons, having operated alternate weeks.

The authors of the earlier papers under discussion speak of this last mentioned installation as an experiment, and seem to imply that if the experiment proves successful, it will be because the cable operated at 16-2/3 cycles and with a current only 2.4 percent of full-load current. The obvious inference to be drawn from this is that the coolness, or low operating temperature, of the cable might in some way operate to prevent the occurrence of any injurious amount of ionization, or might nullify its effect. It seems important to inquire into this reasoning because of its bearing on the other data presented.

Experiments by the authors of the earlier papers here discussed, indicate that when a cable is cold it has a lower ionization voltage than when it is warm. Besides, at any given voltage (provided it lies above the ionization voltage) there will be more energy lost in ionization in cold cable than in warm cable. If failure is to result from ionization, it would not be unnatural to expect it to occur when ionization is present in a large rather than in a relatively small amount. Experiments made by the Company, with which the writers are connected, prove that a high voltage cable, stressed far above the ionization stress, will frequently operate for a long time or continuously at a high temperature, although it will fail within a relatively short time at 20 degrees C.

Thus it would seem that the fact that the Prussian State Railways cable operated at a low temperature would tend to produce failure earlier than if it were operated warm, assuming of course that failure is to result from ionization. And even at 16-2/3 cycles, the loss in ionization at 42 kv per cm. (or over double the value at which ionization is said to begin) would seem to be great enough to insure failure rather nearer the six months than the six years limit. In the light of the data submitted herewith concerning other cables known to have operated successfully for as many as 20 years at a stress of 32 kv per cm., it must be admitted that there is nothing unreasonable in assuming that as far as maximum stress alone is concerned, the Prussian State Railways cables would have operated successfully for many years.

Indirect evidence of the success of this system is obtained from the fact that the Swiss Government Railway has adopted the same system for the electrification of the Gothard Line*, namely 60 000 volts single-phase transmission with the midpoint grounded, so that 30 000 volts is impressed on each of two single conductor cables. The following statement by Dumermuth in connection with this installation is of interest:—

> "The dielectric stress decided upon for the Gothard 30 000 volt cables is about 4000 volts per mm. (40 kv per cm.); this is relatively low in comparison with the stresses customary elsewhere, which are often as high as 5000 volts per mm. (50 kv per cm.)."

While the writers of the present paper are not familiar with any installations which have operated for any considerable length of time with stresses as high as 50 kv per cm., this statement is nevertheless an interesting sidelight.* In this connection a 30 000 volt triplex paper insulated cable for the Societe des Usines a Gaz du Nord & de L'Est was installed in France in October, 1917. The maximum stress at the conductor surface of this cable is 47.5 kv per cm.

The cables in the lists given in Table I represent the experience and judgment of the following foreign and domestic cable makers:—the Standard Underground Cable Company, the John A. Roebling Sons' Company, the General Electric Company, the National Conduit & Cable Company, the Safety Insulated Wire & Cable Company, the American Steel & Wire Company,

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*Schweizerische Bauzeitung, October 18, 1919, p. 193. Dumermuth.

TABLE I—STRESSES IN HIGH VOLTAGE CABLES WHICH HAVE BEEN IN OPERATION FOR FIVE OR MORE YEARS

All Cables Have Round Conductors

Ref. No.	Size of Conductor	Insulation		Working Pressure in Kv	Max. Stress in Kv per cm	User	Installed		No. of Years in Operation
		Thickness each Conductor	Thickness of belt				Where	When	
(TRIPLEX CABLES, PAPER INSULATION)									
35	50 sq. mm.	7.3 mm.	7.3 mm.	30	34.4	Berlin Electric Works	Berlin,	1911	9
5	No. 2	9/32	4/32	25	32.0	St. Paul Gas Light Company	St. Paul, Minn.	1900	20
34	35 sq. mm.	7 mm.	7 mm.	25	31.8	Electrical Works of Treves	Treves, Germany	1913	7
26	35 sq. mm.	9/32	9/32	25	31.3	Ebro Irrigation & Power Company	Barcelona, Spain	1913	7
45	No. 2	9/32	8/32	23	29.5	Northern Ohio Traction & Light Company	Akron, Ohio	1914	6
54	No. 1	9/32	8/32	23	27.8	Northern Ohio Traction & Light Company	Akron, Ohio	1912	8
53	95 sq. mm.	6 mm.	6 mm.	25	27.8	Ebro Irrigation & Power Company	Barcelona, Spain	1913	7
28-A	1/0	9/32	7/32	23	26.4	Edison Elec. Illtg. Company of Detroit	Detroit, Mich.	1911	9
29	No. 2	9/32	8/32	20	25.6	British Columbia Elec. Rwy. Company	Vancouver, Canada	1912	8
31	1/0	9/32	8/32	22	25.3	Winnipeg Elec. Rwy Company	Winnipeg, Canada	1913	7
55	2/0	9/32	8/32	23	25.3	Toledo Rwys. & Lt. Company	Toledo, Ohio	1914	6
28-B	2/0	9/32	7/32	23	25.3	Edison Elec. Illtg. Company of Detroit	Detroit, Mich.	1911	9
6	4/0	10/32	6/32	25	23.5	Montreal Lt., Heat & Power Company	Montreal, Canada	1902	18
51	250 000	9/32	8/32	23	22.5	Northern Ohio Traction & Light Company	Akron, Ohio	1912	8
1	2/0	9/32	6/32	20	22.0	Commonwealth Edison Company	Chicago, Illinois	Before 1908	13
160	No. 6 str.	7/32	5/32	11	20.1	Interborough Rapid Transit Company	New York, N. Y.	1903	17
(SINGLE CONDUCTOR CABLES, PAPER INSULATION)									
37	160 sq. mm.	13 mm.	....	30	42.0	Prussian-Hessian State Rwy	Dessau-Bitterfield	1911	6½ (to end 1917)
36	80 000 cm.	14 mm.	....	30	39.6	Prussian-Hessian State Rwy	Dessau-Bitterfield	1911	6½ (to end 1917)
39	95 sq. mm.	8 mm.	....	14.43	28.2	City of Cologne	Cologne, Germany	1911	9
23	No. 4	18/32	....	12.7	24.4	Great Western Power Company	Sacramento, Cal.	1913	7
(TRIPLEX CABLES, RUBBER INSULATION)									
4	No. 2	7/32	5/32	25	36.7	St. Paul Gas Light Company	St. Paul, Minn.	1900	20
8	No. 1	10/32	....	25	32.5	Shawinigan Water & Power Company	Montreal, Canada	1906 to 1919	13
3	2/0	8/32	7/32	24	28.3	York Haven Water & Power Company	York Haven, Penna.	1909	11
(SINGLE CONDUCTOR CABLES, RUBBER INSULATION)									
7	2/0	14/32	....	14.43	24.0	Shawinigan Water & Power Company	Montreal, Canada	1906 to 1919	13
(TRIPLEX CABLES, VEGETABLE COMPOUND INSULATION)									
27	No. 1	9/32	9/32	25	30.3	Marconi Wireless Company of America	New York, New York	1915	5
32	1/0	9/32	8/32	22	25.3	Winnipeg Elec. Rwy Company	Winnipeg, Canada	1913	7
65	2/0	8/32	8/32	20	23.6	Sao Paulo Tramway Light & Power Company	Sao Paulo, Brazil	1915	5
(SINGLE CONDUCTOR CABLES, VARNISHED CAMBRIC INSULATION)									
11 & 14	No. 2	20/32	....	12.7	20.7	Great Western Power Company	Calif.	1912	8
TRIPLEX CABLES, COMBINATION RUBBER AND VARNISHED CAMBRIC INSULATION									
[illegible]	No. 2	9/32	9/32	25	*32.0	Pacific Light & Power Company	Portland, Oregon	1914	6
[illegible]	No. 2	[illegible]	9/32	25	*30.2	Indiana & Michigan Electric Company	South Bend, Indiana	1911	9
10	No. 2	9/32	9/32	22	*28.2	Great Western Power Company	San Francisco, California	1912	8
17	No. 1	9/32	9/32	22	*26.6	Great Western Power Company	San Francisco, California	1912	8

*Calculated as if insulation were homogeneous.
Actual stress is less, due to relative permittivities of the two materials.

the British Insulated and Helsby Company, W. T. Henley & Company, Johnson & Phillips, Pirelli & Company, Berthoud, Borel & Cie., the Siemens-Schuckert Company, Felton & Guilleaume, Allgemeine Elektricitats Gesellschaft, etc.

IONIZATION DATA ON EARLY CABLES

Tests showing ionization voltages were made by the writers as early as 1913. A quadrant electrometer was used similar to that described by Rayner (I. E. E. 1912) and by Skinner (A. I. E. E. 1902). These tests were made on cables with rubber insulation, varnished cloth insulation and paper insulation impregnated with vegetable and mineral base compounds.

Sample S-729—This piece of single conductor rubber cable was originally tested in February 1914. Its ionization stress at about 20 degrees C. at that time was 19.2 kv per cm. The cable was 4/0 B. & S. insulated with 10/32 inches of rubber. A test on a piece of this original sample made in February 1920, at about the same temperature, gave a slightly higher ionization voltage than before, namely 23 kv per cm. The resistivity of the rubber had trebled however in the intervening six years. The sample was not in operation at any time during that period but lay in the laboratory sample case for the period mentioned, subjected to only the normal heat of a rather warm factory. The 1914 and 1920 measurements on the sample are shown in Fig. 1.

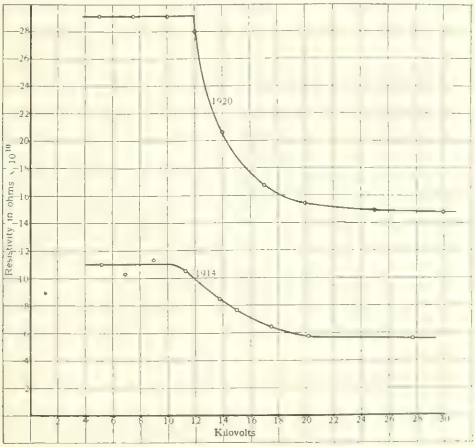

FIG. 1—EFFECT OF TIME ON RESISTIVITY

Sample S-728—This also is rubber and tests in 1920 show an ionization stress of 15.4 kv per cm. The early tests however are incomplete. Ionization must have begun below a stress of 17.3 kv per cm. This specimen doubled in resistivity in the intervening six years.

Samples 7 to 18—These numbers are taken from Shanklin & Matson's paper of 1919. They presumably relate to some of the cables reported on in Shanklin & Clark's paper of June, 1917. Their test results show ionization stresses of unused cable of vegetable compound of 22 kv per cm. at 20 degrees C. and from 16 to 12 kv per cm. for similar cable that had been in use. Samples 16 and 17, with ionization stresses of 14.2 and 12.5 kv per cm. respectively, at 25 to 29 degrees C. were presumably in use at 13.2 kv, three-phase, and thus at a maximum stress of 15.6 kv per cm. several years prior to the date of test. (See Appendix C.).

For mineral base compound cable the results give from 22 to 25 kv per cm. on new cable never in use, and 29 to 32 kv per cm. on cable that had been in use for several years. Cable No. 12 had been in service for five years at 24 kv, three-phase and thus at a maximum stress of 27.6 kv per cm. (See Appendix D).

Klein's Cables—As the writers pointed out in a monograph for private use written in 1913, just after the publication of Klein's paper in the *Elektrotechnische Zeitschrift* of July 31st, 1913, Klein's cables, all of which were new, show the start of ionization at voltages which are the equivalent of from 25 kv per cm. to 31 kv per cm., as shown in Fig. 2.

Sample S-887—This is a piece of one conductor from a three conductor rubber insulated cable that has been in service for over ten years at a maximum stress of about 36.7 kv per cm. When measured on December 31, 1919, and after it had been out of service for about four months, its ionization stress was also 36.7 kv per cm. at 20 degrees C.

Sample K-312—This is a piece of three-conductor, 4/0 paper insulated cable of foreign manufacture that had been in use continuously at about 125 amperes load and a maximum stress of 15.2 kv per cm. from 1904 to 1918. It is of vegetable compound, and of quite low dielectric loss. Its ionization stress when tested on May 5, 1920, three conductors against the sheath, was 14.5 kv per cm. at 24 degrees C.

Sample S-893—This is a sample of three-conductor, 4/0 foreign cable of vegetable base compound, about ten years old, and believed to have been in use at 25 kv, or a maximum stress of about 24 kv per cm., for about eight or nine years. Its ionization stress when tested in February, 1920, was 23.6 kv per cm. at practically all temperatures from 14 to 26 degrees C.

Tests made upon single conductors of this cable ionized at 9 kv, or a stress of 18.5 kv per cm. These single conductor samples were obtained by dissecting the triplex sample just measured. In other words, although ionization began with a maximum stress at the surface of the conductor of 18.5 kv per cm., when the entire conductor insulation was stressed, the ionization point of the triplex cable, measured three conductors against the sheath with single phase voltage was 23.6 kv per cm. A reasonable conclusion to be drawn from this data is that the reason the cable did not show ionization in triplex form until 23.6 kv per cm., was because only the insulation toward the sheath of the cable was under stress. This would indicate that it was the part of the conductor insulation which was toward the center of the cable which ionized at the lower value in this particular case. It must be borne in mind that the insulation toward the center or axis of the cable is subjected to the maximum stress when the cable is operating under three phase voltage. Its three phase ionization point would therefore probably be 18.5 rather than 23.6 kv per cm. The foregoing example indicates the error which may be introduced by assuming a value of the three-phase ionization point from one single-phase test performed upon a triplex cable.

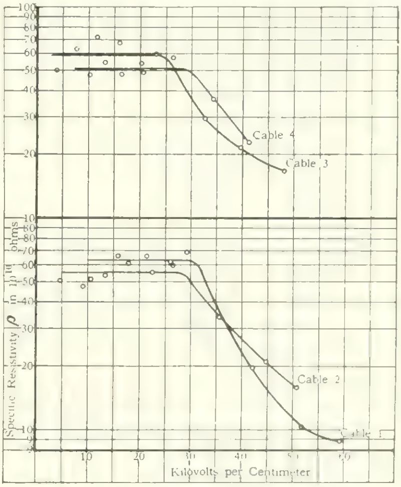

FIG. 2—CHANGE OF RESISTIVITY WITH STRESS AT SURFACE OF CONDUCTOR

Sample K-341—This sample is a piece of foreign made, single-conductor cable of vegetable base compound of reasonably low dielectric loss. It operated from 1914 to 1919 at a maximum stress of 19.3 kv per cm. The neutral of the system was not grounded, however, and the stress may therefore have been as high as 33.4 kv per cm. Its ionization stress on September 2, 1919, was 21 kv per cm.

Sample S-892-2—This sample is a single conductor, insulated with paper, impregnated with mineral base compound by a special process which reduced the air to a minimum, far less air being present in fact than is found in any commercial cable we have examined, made either in this country or abroad. What air there is in it is believed from microscopic examination to be in minute globules, about 0.0005 inches in diameter. These globules were in the body of the paper, not between the layers. It was never in use.

Tests have been made upon the specimen at various times, the specimen in the meantime not being under stress, but lying in the warm laboratory, under compound. On February 9, 1920, at 20 degrees C., ionization commenced at 16.8 kv per cm., the power-factor increasing from 0.5 to 0.82 percent between the maximum stresses of 8.4 kv per cm. and 58.8 kv per cm. On March 16, at 22 degrees C., the ionization stress had risen to 25.2 kv per cm., and the power-factor changed from 0.45 to 0.53 percent between the stresses of 12.6 and 84 kv per cm. On April 4, at 17 degrees C., ionization commenced again at 25.2 kv per cm., the power-factor changing from 0.48 to 0.6 percent between the stresses of 9.3 to 105.0 kv per cm. On April 27, tests at 21 degrees C. showed that the power-factor had improved and that almost no ionization could be detected between stresses of 16.8 and 151.2 kv per cm., between which limits the power-factor changed from 0.33 to 0.35 percent. Most of this change in power-factor occurred at a stress of 84 kv per cm., and possibly that might be considered its ionization stress. The breakdown strength was over 420 kv per cm. at the conductor surface, or far higher than is obtainable in commercial cable insulation.

Sample K-482—This is a piece of three-conductor, foreign, paper-insulated cable of vegetable base compound, which had been in service for about 15 years at a pressure of 25 kv, and a maximum stress of about 24 kv per cm. When tested March 29, 1920, ionization commenced at a gradient of 13 kv per cm. at 17 degrees C., a stress which is considerably below the stress at which the cable operated successfully for such a long time. The cable from which the specimen was cut is still in operation.

Sample S-98—This is a piece of three-conductor vegetable compound paper insulated cable, which on the date of test, December 14, 1914, had been in service about two years at a maximum stress of 27.8 kv per cm. The tests, which were made with single-phase voltage, three-conductors against the sheath, showed that ionization began below 21 kv per cm., probably at about 18 kv per cm., although the tests are not complete enough to be more definite. This specimen had a large amount of ionization, and it is interesting to know that the cable from which it was cut has continued to operate successfully to date, although possibly the large ionization loss is not typical of the remainder of the cable.

Sample S-896—A piece of single conductor, vegetable base compound, paper cable, never in use. When tested in June, 1914, its ionization stress at 19 degrees C. was below 17.1 kv per cm. How much below can not be accurately determined, but it cannot reasonably have been lower than 15 kv per cm. at which value its power-factor would have been 0.8 percent. When a portion of this same piece was tested in February, 1920,, its resistivity at low stresses was a little less than half what it was six years before, but its ionization stress was 15.3 kv per cm. The specimen had been lying in a warm laboratory during the six years.

Sample S-722—This is a piece of vegetable base compound, paper-insulated, three-conductor cable, which had been in service from 1912 to the end of 1917. It was cut out at that time, and the ends of the cable had been sealed up to the time of present tests. The cable had been in operation at 11 000 volts, or a maximum stress of 14.4 kv per cm. When tested April 9, 1920, ionization began at 12.4 kv per cm. at 18 degrees C. The test was performed with three-conductors against the sheath, with single-phase voltage. The cable from which the sample was cut is still in operation.

CONCLUSIONS

The evidence furnished by Table I is conclusive, on one point, namely that a large number of installations, involving large quantities of cable have been operated for many years with the maximum stress at the surface of the conductor far in excess of 19.5 kv per cm. If the evidence furnished by the tests on cable specimens supported the contention that all early cables operated successfully at stresses higher than 19.5 kv per cm. only because their ionization stresses were above their maximum operating stresses, it would unquestionably be wise to limit operating voltages to those values which will give operating stresses below ionization stresses. However, in the above evidence or any other that has thus far been brought forward appears to make this contention convincing.

Klein's tests indicate that in 1913 new paper cables were being produced which had ionization stresses as high as 31 kv per cm.; Shanklin & Matson show 30.2 kv per cm. for cable that has been operating for five years (prior to June, 1917, about the date of their tests); the present authors show 36.7 kv per cm. for a piece of rubber cable which has operated more than ten years; but these values, in face of the considerable amount of evidence showing that new cables of all kinds, either made today or ten years ago, probably have ionization voltages below 22 or 23 kv per cm., must lead us to the conclusion that a very considerable portion, if not all of these large amounts of cable from all parts of the world, and from many different factories, *must be operating* at stresses *well above* the ionization stress.

This conclusion is given further weight when the fact is recalled that early paper cables, say cables made prior to 1912 or 1913 particularly, were much less full of compound than those made today. This in itself proves that they could not have had very high ionization stresses when new; and as the vast bulk of them were made of vegetable compound (although the company with which the writers are connected began making mineral compound cables for high voltage use, in a large scale commercial way, in 1909) it is to be presumed, from Shanklin & Matson's data presented in February, 1919, that such cables should show a lower ionization stress with age and use.

Shanklin & Matson show that with mineral base compound (or possibly we should say a particular type of mineral compound) there is an increase in ionization voltage with age. The Siemens-Schuckert cable for the Prussian State Railways is believed to be of mineral base compound. This is the only one in the list we present which is believed to be of that type. Conceivably therefore, in the Prussian State Railways cable, the ionization stress has increased with time and use.

There is no direct evidence that ageing raises the ionization stress of rubber cable. Tests on S-728 and 729 fail to support this contention. On the other hand S-887 has such a high ionization stress that it strongly suggests that a beneficial ageing effect has taken place.

While it is interesting to speculate on this factor of ageing and the possibility that cables continue to operate satisfactorily at stresses above the ionization stress, it is not necessary for our present purpose to prove that cables improve or deteriorate as regards ionization stress. Neither is it necessary to prove that they have or have not operated at stresses above the ionization stress. The significant fact is that the installations referred to in Table I have operated for many years at maximum stresses far above 19.5 kv per cm., and most of them are operating today.

In connection with ionization stress it must be borne in mind that ionization does not always begin at a clearly defined point. Many cable specimens show ionization curves similar in shape to those shown in Fig. 1. On the other hand, many specimens have shown ionization curves entirely different from this. Some cables have a continuous decrease of resistivity with voltage, with no sharp point. The resistivity of other specimens on the other hand sometimes even increases with voltage. Specimen S-892-2 showed only 0.02 percent of power-factor change between the stress of 16.8 and 151.2 kv per cm. The preceeding remarks all refer to measurements made at room temperature. At higher temperatures the variation in the shape of ionization curve is even more marked and, in general, cables do not have a sharp ionization point at normal operating temperatures.

As to just what significance should be attached to ionization stress we are in doubt. We believe it is of less significance than the amount of ionization, i. e. the watts expended at any given stress above the ionization stress expressed in watts per cu. cm. of insulation. (See *Appendix* E). Even this latter apparently must be multiplied by another factor in some way expressing the relationship between average stress and maximum stress; for two cables having the same ionization stress, and the same watts expended in ionization at a given stress, that cable should fail first, presumably, whose maximum stress most nearly equals its average stress.

We believe that the maximum stress is not a criterion for safe operation any more than the ionization stress is. Incipient failures in three-conductor cables subjected while cold, i.e. at room temperature, for long periods of time to three-phase voltages sufficiently high to make the stress at the surface of the conductor far above the ionization stress plainly indicate that failure most frequently begins at a point where the stress is much lower than the maximum, namely at the surface of contact between conductor insulation and central filler and in the outer wrappings of that portion of the conductor insulation which faces the center of the cable. Thus we are forced to the conclusion that average stress, or stress in and near the fillers (of three-core cable) is more likely to prove to be the proper criterion for safe operation than is the maximum stress. Similar tests on single conductor cable lead us to the same conclusion, for they indicate that incipient failure very frequently occurs not at the point of maximum stress, i.e. the surface of the conductor, but at a point between the surface of the conductor and the sheath, and quite often nearer the sheath than the conductor.

It should be borne in mind that we are here dealing with failures which are in no way attributable to inherent loss in the insulation proper. The failures were due to excessive ionization in air spaces or voids left in the insulation as manufactured, or produced by bending the cable.

Limiting Stresses—The data given here plainly shows that as far as this one factor is concerned, viz. maximum stress at the conductor surface, for cables of average construction we may safely go to 25 or 30 kv per cm. for ordinary three-core cables, and to possibly 40 kv per cm. or higher for single conductor cables.

General Remarks—Klein's data is worth further consideration. Klein himself does not seem to have been aware of the significance of his own data in establishing the existence of ionization or the fact that it was probably the first data published showing the behavior of cable before and after ionization, although Rayner in 1912* showed dielectric loss measurements of internal corona on air enclosed between thin mica plates and Lustgarten in 1913** showed how the very thin layers of air occluded in insulations were stressed in inverse proportion to the permittivities of air and the solid insulation with which it is in contact. It may not be beside the point to remark that it was Klein's paper and our recognition of its significance that led us to make the ionization test on S-729, Fig. 1, early in 1014.

Peek's law of corona had been proposed in 1911. Monasch had shown in 1907 (E. T. Z.) that cable dielectrics among others obeyed a strictly square law for the dielectric loss provided no corona or ionization is present. The thought occurred in reading Klein's paper in 1913 that the approximate adherence to the square law for the lower voltage observation on all six of his cables, and the rapid rise of loss for the higher voltages, was probably due to the fact that at a certain critical voltage on four of them, internal corona began. By plotting Klein's data for power-factor, approximate values were secured for these critical voltages from inspection. It was thought that if the losses at the voltages obviously beyond the critical voltage were taken and if from each observation the inherent loss in the insulation deducted, as obtained from the averages of the readings obviously below the critical voltage correcting them in accordance with the square law proven by Monasch, it might be found that the loss due to corona or ionization would follow some such law as proposed by Peek for corona on wire in air. It is interesting to note that three of the four cables tested, sufficiently far above ionization to give reasonably good data, very accurately followed a quadratic law for the loss in corona. Thus if the loss up to ionization be expressed by an equation of the form AE^2, the loss above ionization may be expressed by an equation, one term of which represents the inherent loss in the solid insulation and of the form AE^2, to which is added a term expressing the loss due to corona of the form $B\ (E-E_0)^2$. The values of E_0 from these equations represent the critical volts or ionization volts and from these values the ionization stresses are figured. These values are not identical with, but agree fairly well with the values obtained by inspection of the power-factor and resistivity curves.

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*I. E. E., p. 3, Vol. 49, 1912.

**I. E. E., p. 235, Vol. 49, 1912.

At the time this work was done in 1913, it was thought that a law had been discovered that would apply to all specimens. However when ionization tests were made shortly afterward, it was found that this was not a fact. While the matter has not been followed up to any great extent since that time, it is considered that about all that can be said is, that the law proposed represents only the minimum loss for a short range above ionization, many specimens of paper cable having been found whose loss in ionization increases more rapidly than the square of the voltage above the value required to start ionization.

In this connection it is interesting to note that two of the rubber specimens referred to above, *S-728* and *S-729*, both have ionization losses which increase only as the first power of the voltage above ionization. The losses in the third rubber specimen *S-887*, did not fall on a smooth curve, and the law of their variation could not be determined. On the other hand, the corona loss in Clark & Shanklin's specimen *9b* made of unfilled varnished cambric increases as the 2.9 power of the voltage above ionization.

APPENDIX A.

One of the authors of the above mentioned papers has published another statement of later date (papers before the New England Section of the N. E. L. A. in September, 1919) in which he recommends certain specific makeups of three-score, high-voltage cable for operation at 10000 to 30000 volts, "and limiting the smallest cable by one giving a tension of about 90 volts per mil at the surface of the conductor." From this data we calculate that the maximum stresses in the solid insulation at working voltages for the cables whose makeups he gives would be as high as 28 kv per cm. It is difficult to reconcile this with the 19.5 kv per cm. recommended by the authors in the earlier papers. It is still more difficult to understand why the limiting tension of 90 volts per mil was used, since 90 volts per mil is equal to 35.4 kv per cm. or nearly double the limit previously given. It will be noted that stresses in the cables which, as stated above, are as high as 28 kv per cm. agree with neither the limit of 19.5 nor 35.4 kv per cm.

APPENDIX B.

Although Shanklin & Matson (A. I. E. E. February, 1919, 182) did not give any figures for the real maximum stress in three conductor cable operating under three phase voltage they were able, following Russell (see his "Alternating Currents") to calculate the voltage gradient between conductor and sheath at the surface of the conductor. This of course does not give the real maximum gradient, that is, the stress at the surface of the conductor at the point nearest the center of the cables, where almost invaribly the maximum stress occurs in three conductor cables under three phase stress.

APPENDIX C.

We identify samples sixteen and seventeen with cables referred to in Fig. 21 of Clark & Shanklin's paper of June, 1917, in which paper it was stated that the cables had been in use for several years.

APPENDIX D.

Sample No. 12 was apparently what was known as Cable No. 4 in Shanklin & Clark's paper of June, 1917 and from that 1917 paper we get the impression that the sample had been in use for five years at 24 kv three phase and thus at a maximum operating stress of 27.6 kv per cm. The ionization stress of a sample of this cable is given as 30.2 kv per cm.

APPENDIX E.

Our conclusion in this regard is not based on any critical experiment, but is the result of converging evidence furnished by different experiments and the accumulated experience of many years in cable work. Briefly this evidence is about as follows:—

A number of short pieces of single conductor cables, impregnated with mineral base compound and vegetable base compound, were tested for power-factor before draining and after draining in 1916 and 1917. The average breakdown strength of both kinds of cables was 100 kv in the undrained condition, and the amount of ionization was small. When drained, the vegetable compound cable averaged about 50 kv for puncture strength; the mineral compound cable averaged about 30 kv. Both cables showed much greater loss due to ionization in the drained condition than in undrained. An examination of the test data does not permit an exact determination of the ionization stress. Mr. R. W. Atkinson has shown, however, that, with a certain type of mineral compound cable of almost identical compound to that referred to above, the ionization stress, before draining and after, is practically the same at 20 degrees C., although it is slightly less at high temperatures in the drained specimen than in the undrained. The loss in ionization was enormously greater in the drained cable than in the undrained. In all of these tests, the draining was produced in such a way that the voids left by the egress of compound were filled with atmospheric air.

Cable made with dry paper but without any impregnation at all may have as high an ionization stress as filled cable or even higher. The amount of ionization, however, is very much greater and it usually fails under test with rapidly applied voltage at a stress but little above the ionization stress. A test on cable of this sort is shown by Mr. Atkinson in his discussion of Clark & Shanklin's paper of June, 1917.

The insistence on the part of buyers of cables for mineral compound, excessively low dielectric losses, and excessively severe bending tests on cold cables is producing now and will for a time at least continue to produce cable that is a greater departure from the cable makers' accumulated experience of many years than, in our judgement, is desirable.

Mr. H. W. Fisher showed in 1909 that the breakdowns on a reel of cable of mineral compound, left standing in a hot place in one position so that the compound would drain away from the upper portion of each convolution into the lower portions, were much lower in the upper or drained portions than in the lower or completely filled portions. The voids in the drained portions were probably filled with air at a pressure less than atmospheric.

Two operating breakdowns occurred in 1915 in three conductor vegetable base compound which had operated successfully for two years at a stress of 13.3 kv per cm. The breakdowns occurred in two parallel cables near the top of a vertical run. Examination of the cables near burnouts gave no evidence of the characteristic charred center of three conductor cable which usually accompanies burnouts due to overheating caused by combined dielectric loss and conductor loss. The cables were found to be quite fully drained of compound near the burnouts. Samples of cable taken from the bottom of the vertical run were full of compound. As the drained upper portions of the cable were quite a distance away from the terminals, which were found to be full of compound, it is to be presumed that the voids in the drained portions were filled with air at pressure below atmospheric. Sample of the drained and undrained portions of the cable were tested for dielectric loss in 1915 and while the drained cable had a somewhat lower dielectric loss below ionization than the filled specimen it had a much higher ionization loss.

Voids produced by draining or by bending cold cable are productive of appreciably reduced breakdown strength; and cable with such voids, particularly if of mineral base compound, seems to be quite susceptible to injury by voltage above the ionization voltage, even when of very short duration, such for instance as may be due to surges during operation or surges caused by a sudden breakdown in another part of the cable. Not only is the cost of producing cable which will not drain at high operating temperatures and which can be bent when cold, greatly increased, but it is debatable whether the user in the end profits enough to warrant the increased risk assumed, particularly when he realizes that cold weather installation of cable can largely be avoided, at least on the big bulk of cable actually used.

In order to meet the cold bending tests, the manufacturer is confronted with the alternative of largely increasing the cost of construction, or using compounds which are thin and lacking in tackiness. It is highly probable he will be forced to do both. But such mineral compounds as he will use, and are being used by the most important American manufacturers today in order to meet the exceedingly low dielectric losses demanded at 100° C. are exceedingly thin at operating temperature, far thinner than any of the vegetable compounds which have been used in the past, and draining of the cable is sure to follow when any considerable vertical length is involved and where it is so located that it must operate at a relatively high temperature. Thus, for high voltage cables operating at stresses above the ionization stress, the amount of ionization will be greatly increased and the cable will be in greatly increased danger of going to destruction, either through the gradual development of ionization faults at operating voltage or through failure due in part or entirely to surges or excess voltage from any cause. On 10 to 12 kv cable the matter is probably not serious if no surges occur, since such cable, with normal insulation thickness, operates at low stresses. On cable for 20 kv and higher with normal insulation thicknesses, the situation is different and serious consideration should be given to such cases.

Considerable amounts of vegetable compound cable which is completely drained but which has operated succesfully for many years, are operating at 10 to 12 kv on slopes and in vertical positions.

Electrical Characteristics of Transmission Circuits-XI

Performance of Long Transmission Lines (Rigorous Solution by Hyperbolic Functions)

Wm. Nesbit

As stated in the discussion of the convergent series solution, the performance of an electric circuit is completely determined by its physical characteristics;—resistance, reactance, conductance and capacitance and the impressed frequency. These five quantities are accurately and fully accounted for in the two complex quantities.

Impedance $Z = R + jX$

Admittance $Y = G + jB$

Having determined the numerical values for these two complex quantities, no further consideration need be given to the physical quantities of the circuit or to the frequency.

In the hyperbolic theory the circuit is said to subtend a certain complex angle, $\theta = \sqrt{ZY}$. This quantity represents in a sense the electrical length of the circuit. The numerical value of this angle θ is expressed in hyperbolic radians. If the circuit is very long electrically the numerical value of the angle will be comparatively large. Conversely, if the circuit is electrically short, it will be comparatively small. The numerical value of the angle θ is, therefore, a measure of the electrical length of the circuit and an indication of how much distortion in the distribution of voltage and current is to be expected as an effect of the capacitance and leakance of the circuit.

In order to give an idea of the extent of the variation in the complex θ and its functions cosh θ and sinh θ for power transmission circuits of various lengths corresponding to 25 and 60 cycle frequencies approximate values have been calculated, as shown in Table O.

This tabulation indicates that for circuits of from 100 to 500 miles in length, operated at frequencies of 25 and 60 cycles, the complex hyperbolic angle of the circuit (which is a plane-vector quantity) has a maximum modulus, or size of 0.41 for 25 cycles and of 1.05 for 60 cycles. It has an argument, or slope, lying between 70 and 78 degrees for 25 cycles and between 80 and 85 degrees for 60 cycles.

In the convergent series solution, the three so-called auxiliary constants A, B and C determine the performance of the circuit. These three auxiliary constants are simply expressions for certain hyperbolic functions of the complex hyperbolic angle θ of the circuit.

Thus

$$A = \cosh\theta$$

$$B = \sinh\theta\sqrt{\frac{Z}{Y}} = Z\frac{\sinh\theta}{\theta} = Z'$$

$$C = \sinh\theta\frac{1}{\sqrt{\frac{Z}{Y}}} = Y\frac{\sinh\theta}{\theta}$$

DETERMINATION OF THE AUXILIARY CONSTANTS

It was shown in Chart XI how values for the auxiliary constants A, B and C may be determined mathematically by convergent series form of solution, using problem X as an example. Chart XVI gives information as to how these same auxiliary constants may be determined by the use of real hyperbolic functions.

The solution for the auxiliary constants by real hyperbolic functions is given completely for problem X in Chart XVI. Vector diagrams are given to assist in following the solution. In the solution for the auxiliary constants by convergent series, the operations were carried out by aid of rectangular co-ordinates of the complex, or vector quantities. In Chart XVI, the operations are to a large extent carried out by the aid of polar co-ordinates. In the case of convergent series, most of the operations consist of adding the various terms of the series together. As addition and subtraction of complex quantities can be most readily carried out when expressed in rectangular co-ordinates, this form of expression is used for the convergent-series solution. On the other hand, powers and roots of complex quantities are most readily obtained by polar coordinate expression. In the solution by real hyperbolic functions Chart XVI, operations for powers and roots predominate, and for this reason polar expressions have been quite generally employed. The solution by real hyperbolic functions is briefly this:—

The impedance Z and the admittance Y are first set down in complex form and their product obtained. The square root of this product gives the complex angle $\theta = \sqrt{ZY}$ of the circuit. This angle is then expressed in rectangular co-ordintes as $\theta_1 + j\,\theta_2$ for the purpose of determining the numerical value of its real part θ_1 (expressed in hyps) and its imaginary or circular part θ_2 expressable in circular radians. This circular part θ_2

TABLE O—GENERAL EFFECT OF DISTANCE AND FREQUENCY UPON THE COMPLEX HYPERBOLIC ANGLE AND ITS FUNCTIONS

LENGTH OF CIRCUIT (MILES)	Z	Y	ZY	$\theta = \sqrt{ZY}$	COSH θ	SINH θ
25 CYCLES						
100	43.3∠50°	0.000 230∠90°	0.00996∠140°	0.[illegible]∠70°	0.99∠0.2°	0.10∠70°
200	80.6∠60°	0.000 430∠90°	0.0346 [illegible]	[illegible]	[illegible]	[illegible]
300	109∠65°	[illegible]	[illegible]733∠155°	[illegible]	[illegible]	[illegible]
400	143∠66°	0.000 900∠90°	[illegible]	[illegible]	[illegible]	[illegible]
500	156∠67°	0.001 100∠90°	[illegible]	[illegible]	[illegible]	[illegible]
60 CYCLES						
100	848∠[illegible]	0.000 560∠90°	0.0474 [illegible]	0.22∠80°	[illegible]	0.22∠80°
200	165∠76°	[illegible]	0.1325 [illegible]	[illegible]	[illegible]	[illegible]
300	244∠77°	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
400	326∠80	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
500	407∠80°	0.002 700∠90°	[illegible]	[illegible]	[illegible]	[illegible]

These values are but roughly approximate to illustrate the general effect for certain circuits.

is converted to degrees by multiplying by 57° .29578. The hyperbolic cosine and sine of this complex angle are next obtained by the aid of logarithms of the functions of the component parts of the hyperbolic complex angle θ. The equation for cosh θ and sinh θ is given just above the solution. With a view of eliminating the necessity of calculation for each complex angle, cosh θ and sinh θ, Dr. Kennelly has prepared tables and charts from which these two functions (and others) may be obtained directly, thus very materially shortening the solution by hyperbolic functions. Since complex angles have two variable components ($\theta_1 + j\ \theta_2$) tables of functions of such angles would have to be quite extensive in order that the steps for which values for the functions are given be not excessive. Although tables of functions of complex angles are not as complete as is desired they are a great help in the solution of ordinary power circuits. Functions corresponding to angles lying between the values for angles in these tables may readily be approximated by simple proportion, giving values sufficiently accurate for ordinary power transmission circuits. They have been calculated in Chart XVI for the purpose of illustrating such procedure and also as a high degree of accuracy was here desired for the purpose of illustrating the agreement of the results as obtained by different rigorous methods. Ordinarily these values would be taken from tables.

CHART XVI – RIGOROUS SOLUTION FOR AUXILIARY CONSTANTS OF PROBLEM X BY REAL HYPERBOLIC FUNCTIONS

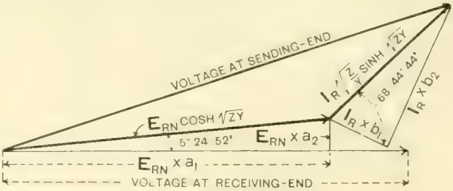
CHARACTERISTICS OF CIRCUIT

LENGTH 300 MILES. CYCLES 60.
CONDUCTORS – 3 # 000 STRANDED COPPER.
SPACING OF CONDUCTORS 10 X 10 X 20 FEET.
EQUIVALENT DELTA SPACING = 12.6 FT.

LINEAR CONSTANTS OF CIRCUIT

TOTAL PER CONDUCTOR

R = 0.350 X 300 = 105 OHMS TOTAL RESISTANCE AT 25° C.
X = 0.830 X 300 = 249 OHMS TOTAL REACTANCE.
B = 5.21 X 300 X 10^{-6} = .001563 MHO TOTAL SUSCEPTANCE.
G = 0 X 300 = 0 MHO TOTAL CONDUCTANCE.
g = (IN THIS CASE TAKEN AS ZERO)



VOLTAGE DIAGRAM

SOLUTION FOR $\theta = \sqrt{ZY}$

$\theta_Z = \tan^{-1}\frac{X}{R} = \tan^{-1}\frac{249}{105} = 67°\ 8'\ 8'$

$Z = R + jX = 105 + j\,249$

$= \sqrt{105^2 + 249^2} = 270.233$

$= 270.233\ \angle 67°\ 8'\ 8'$

$\theta_Y = \tan^{-1}\frac{B}{G} = \tan^{-1}\frac{0.001563}{0} = 90°$

$Y = G + jB = 0 + j\,0.001563$

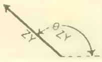
$= \sqrt{0^2 + 0.001563^2} = 0.001563$

$= 0.001563\ \angle 90°$

$\theta_{ZY} = \theta_Z + \theta_Y = 67°\ 8'\ 8' + 90° = 157°\ 8'\ 8'$

$ZY = 270.233 \times 0.001563 = 0.4223745$

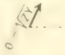
$= 0.4223745\ \angle 157°\ 8'\ 8'$



$\theta = \sqrt{ZY} = 0.6499035\ \angle 78°\ 34'\ 4'$ HYP.

$= 0.128817 + j\,0.637009$ HYP.

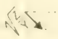
$= (\alpha_1 + j\,\alpha_2)$



$\sqrt{\frac{Z}{Y}} = \sqrt{\frac{270.233\ \angle 67°\ 8'\ 8'}{0.001563\ \angle 90°}}$

$= \sqrt{172893\ \angle{-22°\ 51'\ 52'}}$

$= 415.805\ \angle{-11°\ 25'\ 56'}$



WAVE LENGTH

$\theta_2 = +j\,0.637009$ HYP

$\alpha_2 = \frac{0.637009}{300} = 0.00212336$

WAVE LENGTH $= \frac{2\pi}{\alpha_2} = \frac{6.2831853072}{0.00212336} = 2959$ MILES

SOLUTION FOR (A)

(A) = COSH $\sqrt{ZY}$ = (COSH θ_1 COS θ_2 + j SINH θ_1 SIN θ_2)

$\theta_1 = 0.128817$ HYP $\qquad \theta_2 = \frac{360°}{2\pi} \times 0.637009 = 36°\ 29'\ 52'$

LOG COSH $\theta_1 = 0.003594$ $\qquad$ LOG SINH $\theta_1 = \bar{1}.111172$

LOG COS $\theta_2 = \bar{1}.905194$ $\qquad$ LOG SIN $\theta_2 = \bar{1}.774359$

LOG $a_1 = \bar{1}.908788$ $\qquad$ LOG $a_2 = \bar{1}.885531$

$a_1 = 0.81056$ $\qquad$ $a_2 = 0.07683$

$0.81056 + j\,0.07683$

(A) = 0.8142 $\angle 5°\ 24'\ 52'$

SOLUTION FOR (B)

(B) = $\sqrt{\frac{Z}{Y}}$ SINH $\sqrt{ZY} = \sqrt{\frac{Z}{Y}}$(SINH θ_1 COS θ_2 + j COSH θ_1 SIN θ_2)

LOG SINH $\theta_1 = \bar{1}.111172$ $\qquad$ LOG COSH $\theta_1 = 0.003594$

LOG COS $\theta_2 = \bar{1}.905194$ $\qquad$ LOG SIN $\theta_2 = \bar{1}.774359$

$\bar{1}.016366$ $\qquad$ $\bar{1}.777953$

SINH θ_1 COS $\theta_2 = 0.10383$ $\qquad$ COSH θ_1 SIN $\theta_2 = 0.59973$

$\tan^{-1}\frac{0.59973}{0.10383} = \angle 80°\ 10'\ 40'$

SINH θ_1 COS θ_2 + j COSH θ_1 SIN θ_2 =

$= 0.10383 + j\,0.59973$

$= 0.60865\ \angle 80°\ 10'\ 40'$

$\sqrt{\frac{Z}{Y}} = 415.806\ \angle{-11°\ 25'\ 56'}$

$= 415.805\ \angle{-11°\ 25'\ 56'} \times 0.60865\ \angle 80°\ 10'\ 40'$

(B) = 253.08 $\angle 68°\ 44'\ 44'$

SOLUTION FOR (C)

(C) = $\frac{1}{\sqrt{\frac{Z}{Y}}}$ SINH $\sqrt{ZY}$

$= \frac{1}{415.805\ \angle{-11°\ 25'\ 56'}} \times 0.60865\ \angle 80°\ 10'\ 40'$

$= 0.002405\ \angle 11°\ 25'\ 56' \times 0.60865\ \angle 80°\ 10'\ 40'$

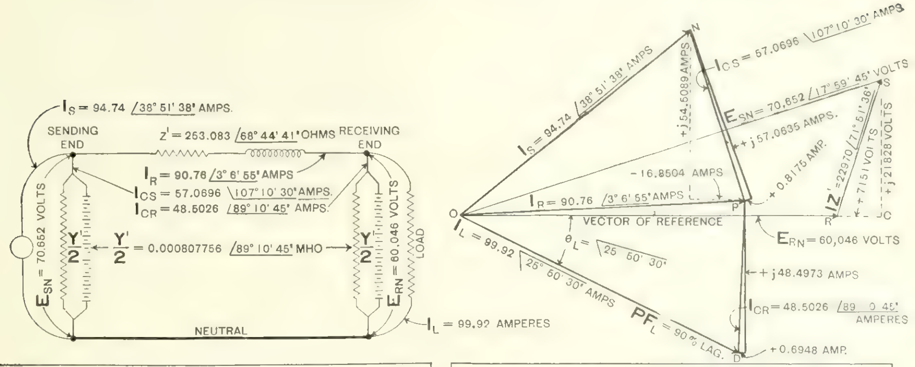
(C) = 0.001464 $\angle 91°\ 36'\ 36'$

As a check against possible serious errors in the calculations, the calculated values may be compared with values read from the Wilkinson Charts. The above results check exactly with those obtained by convergent series. (See Chart XI).

SOLUTION BY NOMINAL π METHOD

By this method, in place of considering the admittance of the circuit as being distributed (as it is in the actual circuit) it is based upon the assumption that the total conductor admittance may be lumped at two points, one half being placed at each end of the circuit. Such

CHART XVII—RIGOROUS EQUIVALENT π SOLUTION OF PROBLEM X


$I_S = 94.74\ \angle 38^\circ 51' 38''$ AMPS.
SENDING END
$Z' = 253.083\ \angle 68^\circ 44' 41''$ OHMS
RECEIVING END
$I_R = 90.76\ \angle 3^\circ 6' 55''$ AMPS
$I_{CS} = 57.0696\ \overline{\backslash 107^\circ 10' 30''}$ AMPS.
$I_{CR} = 48.5026\ \angle 89^\circ 10' 45''$ AMPS.
$\frac{Y'}{2} = 0.000807756\ \angle 89^\circ 10' 45''$ MHO
$\frac{Y'}{2}$
$\frac{Y'}{2}$
$E_{SN} = 70.652$ VOLTS
$E_{RN} = 60.046$ VOLTS
LOAD
NEUTRAL
$I_L = 99.92$ AMPERES
N
$I_S = 94.74\ \angle 38^\circ 51' 38''$ AMPS
$+j54.5089$ AMPS
$I_{CS} = 57.0696\ \overline{\backslash 107^\circ 10' 30''}$ AMPS
$E_{SN} = 70,652\ \angle 17^\circ 59' 45''$ VOLTS
S
$+j57.0635$ AMPS.
$+0.8175$ AMP.
$IZ' = 22970\ \angle 71^\circ 51' 36''$
$+7151$ VOLTS
$+j21828$ VOLTS
-16.8504 AMPS
$I_R = 90.76\ \angle 3^\circ 6' 55''$ AMPS
P
O
VECTOR OF REFERENCE
R
C
$E_{RN} = 60,046$ VOLTS
$\theta_L = \overline{\backslash 25^\circ 50' 30''}$
$I_L = 99.92\ \overline{\backslash 25^\circ 50' 30''}$ AMPS
$+j48.4973$ AMPS
$I_{CR} = 48.5026\ \angle 89^\circ 10' 45''$ AMPERES
$PF_L = 90\%$ LAG.
D
$+0.6948$ AMP.

CHARACTERISTICS OF CIRCUIT

LENGTH. 300 MILES. CYCLES. 60.
CONDUCTORS — 3 # 000 STRANDED COPPER.
SPACING OF CONDUCTORS 10 X 10 X 20 FEET.
EQUAVALENT DELTA SPACING = 12.6 FT.

LINEAR CONSTANTS OF CIRCUIT

FROM TABLES PER MILE

TABLE NO 2. $r = 0.350$ OHM AT 25° C
TABLE NO. 5. $x = 0.830$ OHM (BY INTERPOLATION).
TABLE NO. 10. $b = 5.21 \times 10^{-6}$ MHO (BY INTERPOLATION)
$g =$ (IN THIS CASE TAKEN AS ZERO)

TOTAL PER CONDUCTOR

$R = 0.350 \times 300 = 105$ OHMS TOTAL RESISTANCE.
$X = 0.830 \times 300 = 249$ OHMS TOTAL REACTANCE.
$B = 5.21 \times 300 \times 10^{-6} = .001563$ MHO TOTAL SUSCEPTANCE.
$G = 0 \times 300 = 0$ MHO TOTAL CONDUCTANCE.

SOLUTION FOR HYPERBOLIC ANGLE $\theta = \sqrt{ZY}$

$Z = 105 + j249$ $Y = 0 + j0.001563$
$= 270.233\ \angle 67^\circ 8' 8''$ $= 0.001563\ \underline{|90^\circ}$

$$\theta = \sqrt{270.233\ \angle 67^\circ 8' 8'' \times 0.001563\ \underline{|90^\circ}}$$
$$= \sqrt{0.4223745\ \angle 157^\circ 8' 8''}$$
$$= 0.6499035\ \angle 78^\circ 34' 4''\ \text{HYP.}$$
$$= 0.6499035\ \angle 78^\circ.5678\ \text{HYP.}$$
$$= 0.1288168 + j0.6370092\ \text{HYP.}$$

FROM DR. KENNELLY'S CHARTS

CHART XIX $\frac{\text{SINH}\,\theta}{\theta} = 0.9365365\ \angle 1^\circ.6094 = 0.9365365\ \angle 1^\circ 36' 33''$

CHART XXI $\frac{\text{TANH}\,\theta/2}{\theta/2} = 1.033598\ \overline{\backslash 0^\circ.8206} = 1.033598\ \overline{\backslash 0^\circ 49' 15''}$

★ THESE VALUES WERE CALCULATED IN ORDER TO OBTAIN A HIGH DEGREE OF ACCURACY FOR THE PURPOSE OF DEMONSTRATING THE FUNDAMENTAL ACCURACY OF THIS METHOD.

CORRECTION OF LINEAR CONSTANTS

$Z' = 270.233\ \angle 67^\circ 8' 8'' \times 0.9365365\ \angle 1^\circ 36' 33''$

$= 253.083\ \angle 68^\circ 44' 41''$ (WHICH IS AUXILIARY CONSTANT (B))
$= 91.7486 + j235.866$ OHMS

$Y' = 0.001563\ \underline{|90^\circ} \times 1.033598\ \overline{\backslash 0^\circ 49' 15''}$
$= 0.001615512\ \angle 89^\circ 10' 45''$ MHO

$\frac{Y'}{2} = 0.000807756\ \angle 89^\circ 10' 45''$
$= 0.00001157 + j0.00080767$
$= 1238\ \overline{\backslash 89^\circ 10' 45''}$ OHMS REACTANCE.

CALCULATION OF PERFORMANCE ★

PER PHASE TO NEUTRAL

$KV\text{-}A_{RN} = \frac{18,000}{3} = 6,000.$ $KW_{RN} = \frac{16,200}{3} = 5,400.$

$E_{RN} = \frac{104,000}{1.732} = 60,046.$ $I_R = \frac{6,000 \times 1000}{60,046} = 99.92.$

$PF_R = 90\%$ LAGGING.

RECEIVING-END CONDITIONS

$I_{CR} = 60,046 \times 0.000807756\ \angle 89^\circ 10' 45'' = 48.5026\ \angle 89^\circ 10' 45''$
$= 0.6948 + j48.4973$ AMP.

$I_R = 99.92\,(0.90 - j0.436) + 0.6948 + j48.4973$
$= 90.623 + j4.9322$ AMPS.
$= 90.76\ \angle 3^\circ 6' 55''$ AMPS.

$PF_R = \cos 3^\circ 6' 55'' = 99.85\%$ LEADING.

$KW_{CR} = 60,046\,(0.6948 + j48.4973)$
$= 41.72 + j2912.069$

$KW_{RN} = 6000\,(0.90 - j0.436) + 41.72 + j2912.07$
$= 5441.72 + j296.07$

$I_R Z' = 90.76\ \angle 3^\circ 6' 55'' \times 253.083\ \angle 68^\circ 44' 41''$
$= 22970\ \angle 71^\circ 51' 36''$ VOLTS
$= 7151 + j21,828$ VOLTS

SENDING-END CONDITIONS

$E_{SN} = 60,046 + 7151 + j21828$
$= 67,197 + j21,828$ VOLTS
$= 70,652\ \angle 17^\circ 59' 45''$ VOLTS

$I_{CS} = 70,652 \times 0.000807756\ \angle 89^\circ 10' 45''$
$= 0.8175 + j57.0635$ (TO SUPPLY END VOLTAGE)
$= 57.0696\ \overline{\backslash 107^\circ 10' 30''}$ TO VECTOR OF REFERENCE
$= -16.8504 + j54.5089$

$I_S = (90.623 + j4.9322) + (-16.8504 + j54.5089)$
$= 73.77 + 59.44$ AMPS
$= 94.74\ \angle 38^\circ 51' 38''$ AMPS.

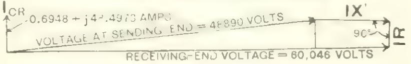
$PF_S = \cos 38^\circ 51' 38'' - 17^\circ 59' 45'' = 93.44\%$ LEADING

$KW_{SN} = 70.652 \times 94.74 \times .9344 = 6255$ KW PER PHASE

$LOSS = 6255 - 5400 = 855$ KW PER PHASE

$EFF = \frac{5400 \times 100}{6255} = 86.33\%$

ZERO LOAD CONDITIONS


I_{CR}
$0.6948 + j48.4973$ AMPS
VOLTAGE AT SENDING END = 48890 VOLTS
IX'
90°
IR
RECEIVING-END VOLTAGE = 60,046 VOLTS

$IR' = (0.6948 + j48.4973) \times 91.7486 = 64 + j4449$ VOLTS

$IX' = (-48.4973 + j0.6948) \times 235.866 = -11438 + j164$

$IR' + IX' = -11374 + 4613$

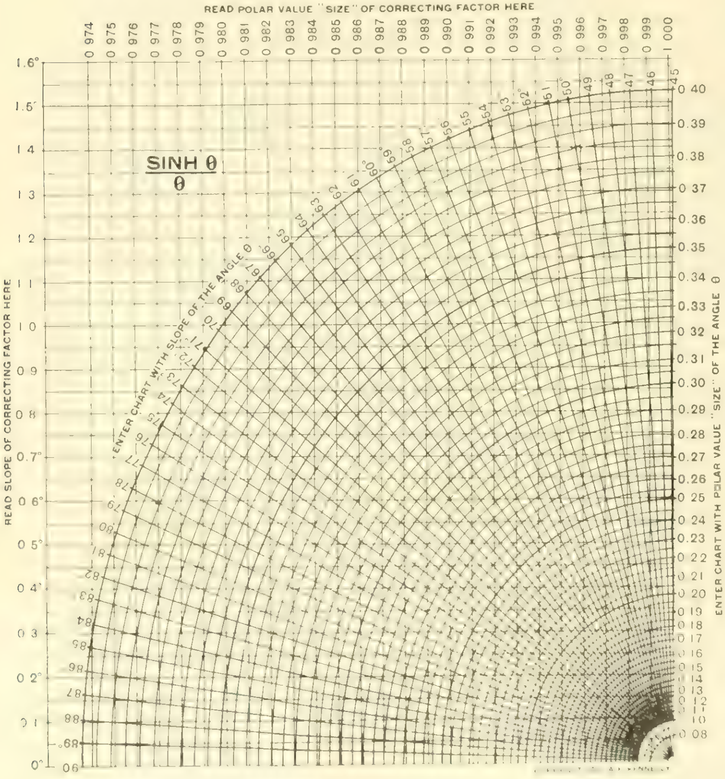
$E_{SNO} = (60,046 - 11373) + 4613 = 48890$ VOLTS $\angle 5^\circ 24' 51''$

*The above results check with those obtained by convergent series. (See Chart XIII).

an artificial circuit is known as a "nominal π" circuit since the nominal values of impedance and admittance are ascribed to this circuit. On the above assumption, the current per conductor is the vector sum of the receiving end load and the receiving end condenser currents. The sending end current is the vector sum of the conductor and the sending end condenser currents. The performance of such a circuit may be determined either graphically or mathematically.

CHART XVIII—KENNELLY CHART FOR IMPEDANCE CORRECTING FACTOR

For angles having polar values between 0 and 0.40.



To find the vector "correcting factor" corresponding to any complex line angle θ, of a circuit, the angle θ is expressed in polar form with the slope in fractional degrees. The correcting factor as read from the chart will be in polar form with its slope in fractional degrees. Consult Table P for rapid conversion to minutes and seconds. For example:—

$\theta = 0.3 \angle 68^\circ$, correcting factor $= 0.9893 \angle 0^\circ.60 = 0.9893 \angle 0^\circ 36' 00''$

$\theta = 0.215 \angle 80^\circ.5$, correcting factor $= 0.9927 \angle 0^\circ.149 = 0.9927 \angle 0^\circ 08' 56''$

If the circuit is not of great electrical length, (say not over 100 miles at 60 cycles or 200 miles at 25 cycles) the performance of the corresponding nominal π circuit will not be materially different from that of the actual circuit having distributed constants which it imitates. If, however, the circuit is of great electrical length the performance of the nominal π circuit no longer closely imitates the performance of the actual circuit which it represents, owing to an error due to the lumpiness of the artificial circuit. Dr. Kennelly has shown that by making certain modifications in the linear or fundamental constants for the impedance and admittance of the nominal π circuit, the lumpiness error will vanish, so that the artificial circuit will then truly represent at the terminals the behavior under steady state operation, taking distributed admittance into account. Such a corrected artificial circuit is known as the "equivalent" π circuit, because it then becomes externally equivalent to the actual circuit, having distributed constants, in every respect.

The complex numbers which must be applied to the impedance, Z and the admittances, $\frac{Y}{2}$ and $\frac{Y}{2}$ of the nominal π circuit in order to correct these nominal values into the equivalent circuit are called the correcting factors of the nominal π circuit. The nominal values of the impedance Z and the admittances $\frac{Y}{2}$ of the circuit must be multiplied by these vector correcting factors in order to convert them into the "equivalent" values; thus:—

$$Z' = Z \frac{\sinh \theta}{\theta}$$

$$\frac{Y'}{2} = \frac{Y}{2} \frac{\tanh \theta/2}{\theta/2}$$

Where $\theta = \sqrt{ZY}$ is the hyperbolic complex angle subtended by the circuit.

Complete tables of hyperbolic functions are not always available; then again, many engineers have a natural aversion to the use of such functions. In order to avoid these objections as well as to simplify calculations, Dr. Kennelly has charted these "correcting factors" for hyperbolic complex angles up to $\theta = 1.0$ radian in steps of 0.01 in size and 1 degree in slope. The writer is particularly indebted to Dr. Kennelly for these charts, which are reproduced herewith for the first time, as Charts XVIII, XIX, XX and XXI. It is believed that the use of these charts will greatly simplify the calculation of the performance of electric power transmission circuits by hyperbolic functions. They enable the vector values of these ratios to be read to at least three decimal places in sizes and to two decimal places in slope, and their availability makes the use of tables of hyperbolic functions unnecessary. The corrected conductor impedance Z' is the same as the familiar auxiliary constant B.

EQUIVALENT π SOLUTION FOR PROBLEM X

The solution for problem X by the equivalent π method is given in Chart XVII. At the top of the sheet are two diagrams, one a diagram for one conductor of the circuit of problem X and the other a corresponding vector diagram of the currents and the voltages at both ends. The numerical values of the angles and the quantities pertaining to problem X are placed upon the two diagrams for the purpose of assisting in following the mathematical solution.

The physical properties of the circuit are first set down, its linear constants obtained from the tables of constants and multiplied by the length of the circuit to obtain the total values per conductor. The next procedure is to calculate the hyperbolic angle θ of the circuit. To do this the impedance and the admittance of the circuit are set down as complex quantities in the form of polar coordinates and multiplied together by multiplying their slopes and adding their angles. The square root of the resulting vector is obtained by taking the square root of the slope and halving the angle. The result is the hyperbolic angle θ of the circuit expressed in hyps.

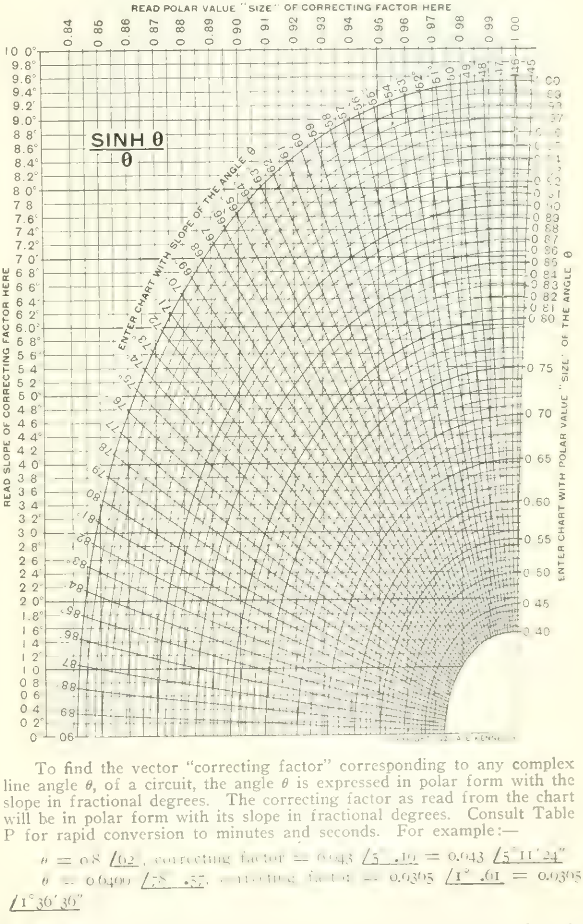
The ratio charts XIX and XXI are next consulted and the correcting values $\frac{\sinh\,\theta}{\theta}$ and $\frac{\tanh\,\theta/2}{\theta/2}$ corresponding to the hyperbolic angle of the circuit read off. Having thus obtained the correcting factors corresponding to this circuit, the linear impedance Z and linear admittance Y per conductor are multiplied respectively by the sinh and the tanh correcting factors.

If the circuit under consideration is electrically short the effect of these correcting factors upon the linear constants will be small and possibly negligible but, as the circuit becomes longer, their effect becomes increasingly greater. The effect of the correcting factors for problem X is to change the linear impedance Z from $270.233\ \underline{/67^\circ\ 08'\ 08''}$ to $Z' = 253.983\ \underline{/68^\circ\ 44'\ 41''}$ and to change the linear admittance Y from $0.001563\ \underline{/90^\circ}$ to $Y' = 0.001615512\ \underline{/89^\circ\ 10'\ 45''}$. In other words this circuit will behave in the steady state at 60 cycles as though its conductor resistance were reduced from 105 to 91.7486 ohms and its inductive reactance reduced from 249 to 235.866 ohms. Similarly it will behave as though a non-inductive leak of 11.571 micromhos, has been applied to each condenser in shunt.

In order to illustrate the exact agreement in the results as obtained by the equivalent π method with those obtained by either the convergent series or pure hyperbolic solution, the ratio values used for this problem were calculated and not obtained graphically. The accuracy in the performance resulting from the use of ratio values taken from the charts is well within the requirements of practical power circuits. The mathematical solution for these factors is given in Fig. 48.

CHART XIX—KENNELLY CHART FOR IMPEDANCE CORRECTING FACTOR

For angles having polar values between 0.40 and 1.0.



To find the vector "correcting factor" corresponding to any complex line angle θ, of a circuit, the angle θ is expressed in polar form with the slope in fractional degrees. The correcting factor as read from the chart will be in polar form with its slope in fractional degrees. Consult Table P for rapid conversion to minutes and seconds. For example:—

$\theta = 0.8\ \underline{/62}$, correcting factor $= 0.943\ \underline{/5^\circ.19} = 0.943\ \underline{/5^\circ\,11'\,24''}$

$\theta = 0.6400\ \underline{/78^\circ.57}$, correcting factor $= 0.9305\ \underline{/1^\circ.61} = 0.9305\ \underline{/1^\circ\,36'\,36''}$

Having determined the corrected values for the impedance Z' and the admittance Y' which will produce exact results, the remainder of the solution may be carried out graphically as indicated by the vector diagram in the upper right hand part of Chart XVII or mathematically as indicated under this vector diagram.

EQUIVALENT T SOLUTION

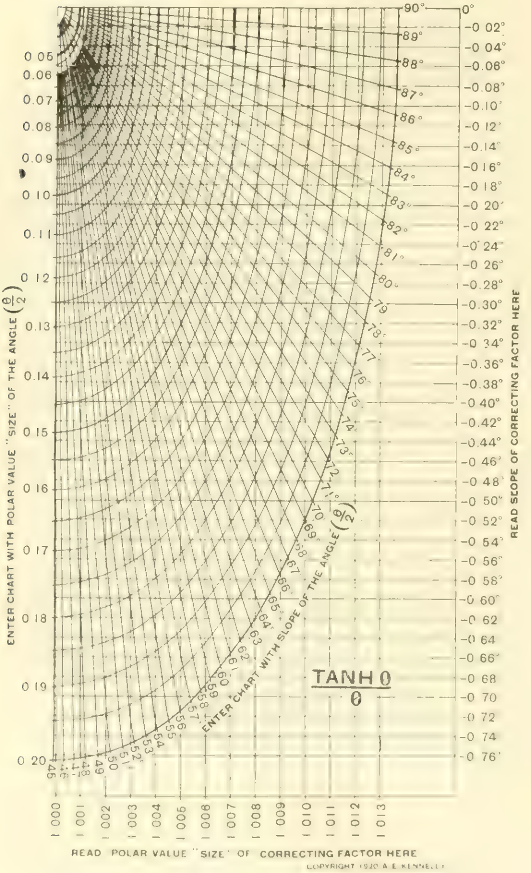
Dr. Kennelly has shown that the correcting factors which convert the nominal π into the equivalent π of the conjugate smooth line, are the same as those which convert the nominal T into the equivalent T, but in inverse order;—that is the correcting factors for the nominal T line are

$$Z' = Z \frac{\tanh \theta/2}{\theta/2}$$

$$Y' = Y \frac{\sinh \theta}{\theta}$$

CHART XX—KENNELLY CHART FOR ADMITTANCE CORRECTING FACTOR

For angles having polar values between 0 and 0 20.



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To find the vector correcting factor corresponding to any complex line angle θ of a circuit, the angle θ is expressed in polar form with the slope in fractional degrees. The angle of the line, θ, is then divided by 2 $\left(\frac{\theta}{2}\right)$ as it is necessary to enter the admittance charts with half the angle θ. The correcting factor as read from the chart will be in polar form with its slope in fractional degrees. Con sult Table P for rapid conversion to minutes and seconds. For example:—

$\theta = 0.4 \angle 61$, $\left(\frac{\theta}{2}\right) = 0.2 \angle 61$, correcting factor $= 1.007 \overline{\backslash 0^\circ .655}$ $= 1.007 \overline{\backslash 0^\circ 39' 18''}$

$\theta = 0.326 \angle 75^\circ .5$ $\left(\frac{\theta}{2}\right) = 0.163 \angle 75^\circ .5$, correcting factor $= 10078$ $\overline{\backslash 0^\circ .25} = 10078 \overline{\backslash 0^\circ 15' 00''}$

Either the equivalent π or the equivalent T solution may be used by applying the two correcting factors properly. Usually less arithematical work will be required for the equivalent π solution.

ELECTRICAL CONDITIONS AT INTERMEDIATE POINTS

In the foregoing, the behavior of circuits at their terminals has been considered. In some cases it may be desirable to predetermine the voltage and the current at points along the circuit between the terminals. This may be particularly desirable in case of circuits of great electrical length and consequently having a pronounced bend or hump in the voltage graphs representing the voltage at points along the circuit. In Fig. 21 voltage and current graphs were shown for the circuit of problem X corresponding to zero load; also load conditions. Accompanying this stated was the step-by-step method by which the current and voltage at these intermediate points had been determined. In a corresponding manner the intermediate electrical conditions may be determined by the employment of hyperbolic functions. It is usual, however, when employing hyperbolic functions for determining the voltage or the current at points along a smooth circuit, in the steady state, to take advantage of the following facts relative to the variation in current and potential from point to point in such a circuit.

The potentials of any and all points of such a circuit are as the sines and the currents as the cosines of the corresponding position angles. This means that if the position angles corresponding to two points of a smooth circuit in the steady state are known, and the voltage or the current at one of these points is also known, then the voltage or current at any other point will be directly proportional to the sine or the cosine respectively of the corresponding position angles. In a similar manner, the impedance follows the tangents, the admittance the cotangents and the volt-amperes the sines of twice the angles. Herein lines the beauty of the application of hyperbolic functions of complex angles for determining the electrical performance of electric circuits. The relationship expressed above (taken from Dr. Kennelly's "Artificial Electric Lines") are given in equation form below for ready reference:—

$$\frac{E_p}{E_c} = \frac{\sinh \theta_p}{\sinh \theta_c} \text{ numeric}$$

$$\frac{I_p}{I_c} = \frac{\cosh \theta_p}{\cosh \theta_c} \text{ numeric}$$

$$\frac{Z_p}{Z_c} = \frac{\tanh \theta_p}{\tanh \theta_c} \text{ numeric}$$

$$\frac{Y_p}{Y_c} = \frac{\coth \theta_p}{\coth \theta_c} \text{ numeric}$$

$$\left|\frac{Kv\text{-}a_p}{Kv\text{-}a_c}\right| = \left|\frac{sinh\ 2\ \theta_p}{sinh\ 2\ \theta_c}\right|_{numeric}$$

Where p and c are points along the circuit, c being some point where the electrical conditions are known, and p the point for which they are to be computed. The vertical lines enclosing the two parts of the last equation are for the purpose of indicating that the "size" of these complex quantities are referred to in this equation.

POSITION ANGLES

Reference has been made to the line as subtending a certain complex hyperbolic angle θ. Since the circuit through the load also encounters resistance and reactance, the load may be said to subtend also a certain complex hyperbolic angle, so that the receiving end of the circuit occupies an angular position θ_r. The total angle of the circuit (line and load) will be $\theta_r + \theta = \theta_s$. By similar reasoning all points lying between the receiving and sending ends of a line will occupy or assume an angular position θ_p. If that part of the linear angle θ of the line between the receiving end and the point p be designated as θ_{pr}, then the angular position of the point p will be $\theta_p = \theta_r + \theta_{pr}$. Thus, at a point in the middle of the line, the position angle will be $\theta_p = \theta_r + \theta_{pr} = \theta_r + \theta/2$.

If the line is grounded or short-circuited at the receiving end, there will be no load containing resistance and reactance, and consequently no load angle. In such case $\theta_r = o$ and the distribution of position angles along the line will be purely a linear function of the total line angle o. In such a case $\theta_s = o$.

Load Conditions—In Fig. 49 the procedure is shown which may be followed for determining by complex functions of position angles the current and the voltage vectors at points 25 miles apart along problem X circuit, under load conditions.

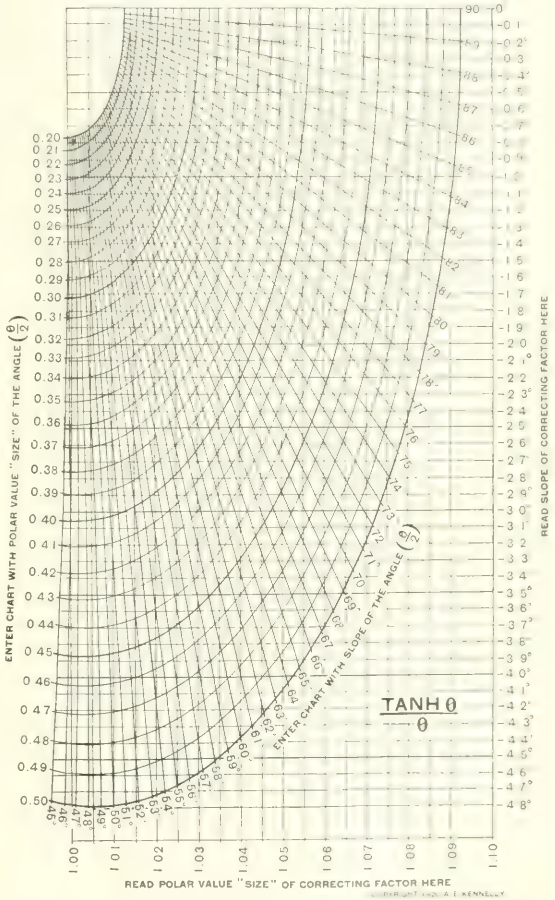
The procedure is first to determine the complex angle θ_r at the receiving end resulting from the load. The mathematical determination of this load angle is tedious. Such determination is given for problem X circuit under stated load in Fig. 49. This complex angle θ_r of the load (that is the position angle at the receiving end) is such that its complex tangent equals the impedance load δ to ground, or zero potential, at the receiving end of line (ohms $\angle$) divided by the surge impedance Z_0 of a conductor (ohms $\angle$). That is,—

$$tanh\ \theta_r = \frac{\delta}{Z_0}$$

Since we are here interested only in the ratio between the load impedance and the surge impedance, the values may be taken either per unit length or total per conductor. Although tanh θ_r is readily calculated, as may be seen by consulting Fig. 49, the subsequent calculation for the corresponding angle θ_r is tedious. After having calculated the tanh θ_r, the corresponding angle θ_r may be obtained with sufficient accuracy from a table of tangents of complex angles or, more readily still,

CHART XXI—KENNELLY CHART FOR ADMITTANCE CORRECTING FACTOR

For angles having polar values between 0.20 and 0.50.



To find the vector correcting factor corresponding to any complex line angle θ, of a circuit, the angle θ is expressed in polar form with the slope in fractional degrees. The angle of the line θ is then divided by 2 $\left(\frac{\theta}{2}\right)$ as it is necessary to enter the admittance charts with half the angle θ. The correcting factor as read from the chart will be in polar form with its slope in fractional degrees. Consult Table P for rapid conversion to minutes and seconds. For example:—

$\theta = 0.84\ \underline{/60}$, $\left(\frac{\theta}{2}\right) = 0.42\ \underline{/60}$, correcting factor $= 1.045\ \overline{\backslash 2^\circ .4} = 1.045\ \overline{\backslash 2^\circ 41' 00''}$

$\theta = 0.6496\ \underline{/78^\circ .568}$, $\left(\frac{\theta}{2}\right) = 0.3250\ \underline{/78^\circ .568}$, correcting factor $1.034\ \overline{\backslash 0^\circ .83} = 1.034\ \overline{\backslash 0^\circ 49' 48''}$

from a chart of such functions.* After having determined the angle θ_r by consulting a chart of tangents of complex angles, or by mathematical calculation, as in Fig. 49, the position angles at points along the circuit may easily and readily be determined as follows:—

The change in the position angle from point to point along the circuit, due to the line impedance and the line admittance is purely a linear function of the line angle θ. This is the case whether the line is grounded, loaded or free at the receiving end.

TABLE P—SUBDIVISIONS OF A DEGREE

SECONDS TO DEGREES		MINUTES TO DEGREES		DEGREES TO MINUTES AND SECONDS					
″ =	°	′ =	°	° =	′	″	° =	′	″
01	0.0003	01	0.0167	0.001	00	03.6	0.006	00	21.6
02	0.0006	02	0.0333	0.002	00	07.2	0.007	00	25.2
03	0.0008	03	0.0500	0.003	00	10.8	0.008	00	28.8
04	0.0011	04	0.0667	0.004	00	14.4	0.009	00	32.4
05	0.0014	05	0.0833	0.005	00	18.0	0.010	00	36.0
06	0.0017	06	0.1000						
07	0.0019	07	0.1167						
08	0.0022	08	0.1333						
09	0.0025	09	0.1500						
10	0.0028	10	0.1667						
11	0.0031	11	0.1833	0.01	00	36	0.51	30	36
12	0.0033	12	0.2000	0.02	01	12	0.52	31	12
13	0.0036	13	0.2167	0.03	01	48	0.53	31	48
14	0.0039	14	0.2333	0.04	02	24	0.54	32	24
15	0.0042	15	0.2500	0.05	03	00	0.55	33	00
16	0.0044	16	0.2667	0.06	03	36	0.56	33	36
17	0.0047	17	0.2833	0.07	04	12	0.57	34	12
18	0.0050	18	0.3000	0.08	04	48	0.58	34	48
19	0.0053	19	0.3167	0.09	05	24	0.59	35	24
20	0.0055	20	0.3333	0.10	06	00	0.60	36	00
21	0.0058	21	0.3500	0.11	06	36	0.61	36	36
22	0.0061	22	0.3667	0.12	07	12	0.62	37	12
23	0.0064	23	0.3833	0.13	07	48	0.63	37	48
24	0.0067	24	0.4000	0.14	08	24	0.64	38	24
25	0.0069	25	0.4167	0.15	09	00	0.65	39	00
26	0.0072	26	0.4333	0.16	09	36	0.66	39	36
27	0.0075	27	0.4500	0.17	10	12	0.67	40	12
28	0.0078	28	0.4667	0.18	10	48	0.68	40	48
29	0.0081	29	0.4833	0.19	11	24	0.69	41	24
30	0.0083	30	0.5000	0.20	12	00	0.70	42	00
31	0.0086	31	0.5167	0.21	12	36	0.71	42	36
32	0.0089	32	0.5333	0.22	13	12	0.72	43	12
33	0.0092	33	0.5500	0.23	13	48	0.73	43	48
34	0.0094	34	0.5667	0.24	14	24	0.74	44	24
35	0.0097	35	0.5833	0.25	15	00	0.75	45	00
36	0.0100	36	0.6000	0.26	15	36	0.76	45	36
37	0.0103	37	0.6167	0.27	16	12	0.77	46	12
38	0.0106	38	0.6333	0.28	16	48	0.78	46	48
39	0.0108	39	0.6500	0.29	17	24	0.79	47	24
40	0.0111	40	0.6667	0.30	18	00	0.80	48	00
41	0.0114	41	0.6833	0.31	18	36	0.81	48	36
42	0.0117	42	0.7000	0.32	19	12	0.82	49	12
43	0.0119	43	0.7167	0.33	19	48	0.83	49	48
44	0.0122	44	0.7333	0.34	20	24	0.84	50	24
45	0.0125	45	0.7500	0.35	21	00	0.85	51	00
46	0.0128	46	0.7667	0.36	21	36	0.86	51	36
47	0.0130	47	0.7833	0.37	22	12	0.87	52	12
48	0.0133	48	0.8000	0.38	22	48	0.88	52	48
49	0.0136	49	0.8167	0.39	23	24	0.89	53	24
50	0.0139	50	0.8333	0.40	24	00	0.90	54	00
51	0.0142	51	0.8500	0.41	24	36	0.91	54	36
52	0.0144	52	0.8667	0.42	25	12	0.92	55	12
53	0.0147	53	0.8833	0.43	25	48	0.93	55	48
54	0.0150	54	0.9000	0.44	26	24	0.94	56	24
55	0.0153	55	0.9167	0.45	27	00	0.95	57	00
56	0.0156	56	0.9333	0.46	27	36	0.96	57	36
57	0.0159	57	0.9500	0.47	28	12	0.97	58	12
58	0.0162	58	0.9667	0.48	28	48	0.98	58	48
59	0.0164	59	0.9833	0.49	29	24	0.99	59	24
60	0.0167	60	1.0000	0.50	30	00	1.00	60	00

EXAMPLES

$0°.41 = 0° 24' 36''$ $0° 41' 00'' = 0°.6833.$
$0°.005 = 0° 00' 18''$ $0° 00' 46'' = 0°.0128.$

Referring to Fig. 49, the angular position of the receiving end, due to the load conditions assumed, was calculated to be 0.48047 + j 1.06354. It is therefore necessary to add this angle to each of the linear line angles of the various points along the line in order to obtain the position angles of the points in question. Thus the linear line angle of the middle point of the circuit is 0.0644084 + j 0.3185046 and adding to this the load angle 0.48047 + j 1.06354 gives 0.544874 + j 1.3820446, which corresponds with the entry in the tabulation of Fig. 51 for the position angle at the middle of the circuit. In a similar manner position angles for the load assumed are readily determined for points 25 miles apart. Having determined the position angles for the various points along the circuit, the sines and the cosines corresponding to these position angles may be approximated closely from tables or charts of such complex functions, or may be calculated accurately by following the equations at the lower left hand corner of Fig. 51. Since the receiving end voltage and current are known to be 60 046 volts and 99.92 amperes respectively, the voltage and currents at all other points of this circuit will be as the sines and cosines of the corresponding position angles. From the vector quantities that have been assigned to the voltage and current at the points along the circuit, the power-factors at these points are readily determined.

The current and voltage graphs at the bottom of Fig. 51 were plotted from values as determined by the use of functions of position angles. These check exactly with similar graphs as determined by the Wilkinson charts and step-by-tep process (See Fig. 21).

Zero Load Condition—The procedure which may be followed for determining the position angles under zero load, their functions and the corresponding current and voltage distribution is the same as given above for load conditions and is shown in Fig. 50. In this case, however, there is no load and consequently no real part to the load angle. On the other hand the impedance of the load is infinite, that is $\delta = \infty$ so that $\theta_r = \tanh^{-1}\frac{\infty}{Z_0} = j\frac{\pi}{2}$. The effect of this supersurge impedance load at the receiving end at zero load is to cause a phase rotation of 90 degrees or one quadrant, $j\frac{\pi}{2} = 1.57080$ circular radians. Thus, at zero load, $\theta_{r0} = \left(0 + j\frac{\pi}{2}\right) = 0 + j\,1.57080$ and this angle must be added to each of the linear position angles of the points along the line. With the position angles corresponding to zero load thus obtained, and assigned to the points along the circuit, the voltage will be found to follow the sines, and the current the cosines, etc. of these position angles.

POLAR DIAGRAM OF CURRENT VOLTAGE

In Fig. 52 are shown the polar graphs of the voltage and the current for problem *X*, corresponding to load, and also to zero load conditions. These polar graphs were plotted from the vector values for current and voltage as tabulated in Figs. 49 and 50 for each 25 miles of circuit.

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*Such as that worked out by Dr. Kennelly and published by the Harvard University Press. The chart atlas referred to contains graphs of complex tangents of complex angles, and by following the chart in the reverse from the usual direction the complex angle corresponding to any complex tangent may be read off directly.

EFFECT OF HARMONIC CURRENTS AND VOLTAGES

The foregoing discussion is based upon the assumption that the fundamental wave is of sine shape and consequently free from harmonics. If harmonics of considerable magnitude are present in the fundamental wave, then it will be necessary to take their effect into account, if high accuracy is essential. In such a case there is an independent solution required of potential and current for each single frequency in turn, as though the others did not exist, and then the r.m.s. value at

PROBLEM "X"

$R = 105 \text{ OHMS.} \quad X = 249 \text{ OHMS.}$

$G = 0 \text{ MHO.} \quad Y = 0.001563 \text{ MHO.}$

$$Z = 270.233 \underline{/67^\circ 08' 08''}$$

$$Y = 0.001563 \underline{|90^\circ}$$

$$\theta = \sqrt{ZY} = \sqrt{0.422\,374\,5 \underline{/157^\circ 08' 08''}}$$
$$= 0.649\,903\,5 \underline{/78^\circ 34' 04''}$$
$$= 0.1288168 + j0.637\,0092$$

CALCULATION FOR $\frac{\text{SINH } \theta}{\theta}$

$$\text{SINH } \theta = 0.103\,8393 + j0.599735$$
$$= 0.6086583 \underline{/80^\circ 10' 38''} \quad *$$
$$\frac{\text{SINH}\,\theta}{\theta} = \frac{0.6086583 \underline{/80^\circ 10' 37''}}{0.649\,903\,5 \underline{/78^\circ 34' 04''}}$$
$$= 0.936\,536\,5 \underline{/1^\circ 36' 33''}$$
$$= \text{IMPEDANCE CORRECTING FACTOR.}$$

CALCULATION FOR $\frac{\text{TANH}(\theta/2)}{\theta/2}$

$$\frac{\theta}{2} = 0.324\,951\,8 \underline{/78^\circ 34' 04''}$$
$$= 0.064\,4084 + j0.318\,504\,6$$
$$\text{SINH}\frac{\theta}{2} = 0.061\,211\,22 + j0.313\,7963$$
$$= 0.319\,710\,7 \underline{/78^\circ 57' 43''}$$
$$\text{COSH}\frac{\theta}{2} = 0.951\,6754 + j0.020\,1832$$
$$= 0.951\,889\,4 \underline{/1^\circ 12' 54''}$$
$$\text{TANH}\frac{\theta}{2} = \frac{\text{SINH}(\theta/2)}{\text{COSH}(\theta/2)} = \frac{0.319\,710\,7 \underline{/78^\circ 57' 43''}}{0.951\,8894 \underline{/1^\circ 12' 54''}}$$
$$= 0.335\,869\,6 \underline{/77^\circ 44' 49''}$$
$$\frac{\text{TANH}(\theta/2)}{\theta/2} = \frac{0.335\,869\,6 \underline{/77^\circ 44' 49''}}{0.324\,951\,8 \underline{/78^\circ 34' 04''}}$$
$$= 1.033\,598 \overline{\backslash 0^\circ 49' 15''}$$
$$= \text{ADMITTANCE CORRECTING FACTOR.}$$

$$\underline{\text{CHECK}},\ \text{SINH}\,\theta = 2\ \text{SINH}\frac{\theta}{2}\ \text{COSH}\frac{\theta}{2} = 2 \times .03197107 \underline{/78^\circ 57' 44''} \times 0.951\,8894 \underline{/1^\circ 12' 54''}$$
$$= 0.608\,6584 \underline{/80^\circ 10' 38''} \text{ (WHICH CHECKS WITH *).}$$

FIG. 48—MATHEMATICAL DETERMINATION OF CORRECTING FACTORS FOR EQUIVALENT π SOLUTION

PROBLEM "X"

$$Z = 105 + j249 = 270.233 \underline{/67^\circ 08' 08''} \text{ OHMS.}$$
$$Y = 0 + j0.001563 = 0.001563 \underline{|90^\circ} \text{ MHO.}$$
$$\theta = \sqrt{ZY} = 0.1288168 + j0.6370092 \text{ HYP.}$$
$$\text{KV-A}_{RN} = 6000\,000 \overline{\backslash 25^\circ 50' 31''} \text{ WATTS.}$$
$$= 5\,400\,000 - j2\,615\,340.$$
$$E_{RN} = 60044.4 \text{ VOLTS TO NEUTRAL.}$$
$$I_R = 99.92605 \overline{\backslash 25^\circ 50' 31''}$$

SOLUTION FOR TANH θ_R

$$\delta = \frac{E_{RN}}{I_R} = 600.888 \underline{/25^\circ 50' 31''} \text{ OHMS.}$$
$$\dot{Z_0} = \sqrt{\frac{Z}{Y}} = 415.805 \overline{\backslash 11^\circ 25' 56''} \text{ OHMS.}$$
$$\text{TANH } \theta_R = \frac{600.888 \underline{/25^\circ 50' 31''}}{415.805 \overline{\backslash 11^\circ 25' 56''}}$$
$$= 1.44512 \underline{/37^\circ 16' 27''}$$
$$= 1.14995 + j0.875209 \quad *$$
$$= (\theta_1 + j\theta_2)$$

SOLUTION FOR ANGLE θ_R

$$\text{TANH}^{-1}(\theta_1 \pm j\theta_2) = \frac{1}{2}\,\text{LOGH}\sqrt{\frac{(1+\theta_1)^2 + \theta_2^2}{(1-\theta_1)^2 + \theta_2^2}} + j\left[\frac{\pi - \text{TAN}^{-1}\left(\frac{\theta_1 + 1}{\pm\theta_2}\right) + \text{TAN}^{-1}\left(\frac{\theta_1 - 1}{\pm\theta_2}\right)}{}\right]$$

$$\theta_R = \frac{1}{2}\,\text{LOGH}\sqrt{\frac{(1+1.14995)^2 + 0.875209^2}{(1-1.14995)^2 + 0.875209^2}} + j\,\frac{\left(180^\circ - \text{TAN}^{-1}\frac{2.14995}{0.875209} + \text{TAN}^{-1}\frac{0.14995}{0.875209}\right)}{2}$$

$$= \frac{1}{2}\,\text{LOGH}\sqrt{\frac{4.62229 + 0.76599}{0.022485 + 0.76599}} + j\,\frac{(180^\circ - 67^\circ 50' 58'' + 9^\circ 43' 20'')}{2}$$

$$= \frac{1}{2}(\text{LOGH } 2.61415) + j\,60^\circ 56' 11''$$
$$= \frac{1}{2}(0.960939) + j1.0635397$$

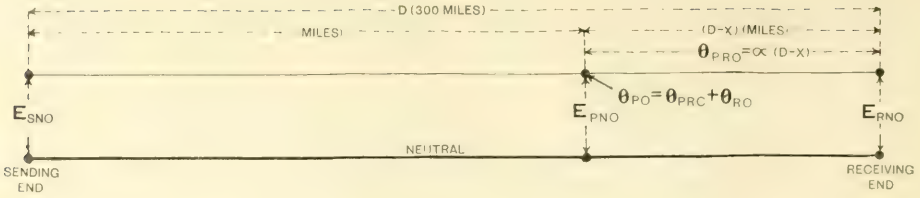
$$\theta_R = 0.4804695 + j1.0635397$$
$$\theta = \underline{0.1288168 + j0.6370092}$$
$$\theta_S = 0.6092863 + j1.7005489$$

$\underline{\text{CHECK}}$

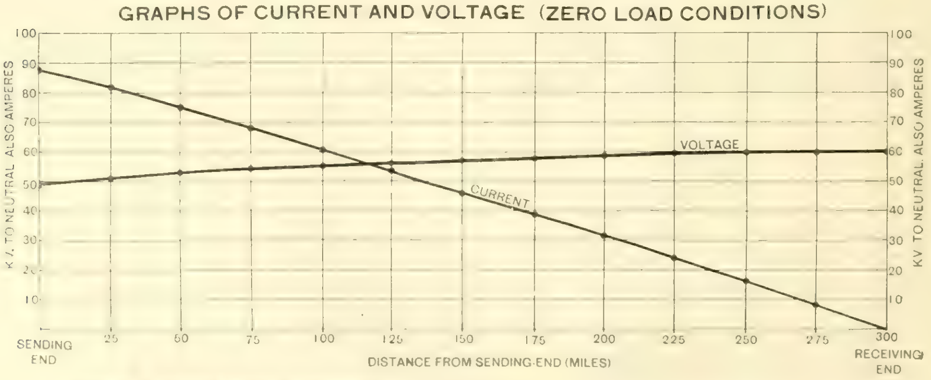
$$\text{SINH } \theta_R = 1.006572 \underline{/76^\circ 03' 36''}$$
$$\text{COSH } \theta_R = 0.69653 \underline{/38^\circ 47' 09''}$$
$$\text{TANH } \theta_R = \frac{\text{SINH } \theta_R}{\text{COSH } \theta_R} = \frac{1.006572 \underline{/76^\circ 03' 36''}}{0.69653 \underline{/38^\circ 47' 09''}}$$
$$= 1.14995 + j0.875209 \text{ (WHICH CHECKS WITH *).}$$

FIG. 49—POSITION ANGLE θ_R AT RECEIVING-END

Mathematical determination at load conditions.



(D-X) MILES	X MILES	POSITION ANGLE $\theta_{PO} = \theta_{PRO} + \theta_{RO}$	SINH θ_{PO} (THE VOLTAGE FOLLOWS THIS COMPLEX FUNCTION)	E_{PNO} VOLTS ∠	COSH θ_{PO} (THE CURRENT FOLLOWS THIS COMPLEX FUNCTION)	I_{PO} AMPERES ∠	PF_{PO} %
0	300	0 + j1.57080 θ_2 = 90°00'00''	0 + j1.00000 = 1.00000 ∠90°	60046 ∠0°	0 0 ∠90°	0 ∠11°25'56''	
25	275	0.01073 + j1.62388 θ_2 = 93°02'29'	0.00[illegible] + j[illegible] = 0.99[illegible]05 ∠89°[illegible]'03''	[illegible] ∠0°0[illegible]'5[illegible]''	0.0530[illegible] + j0.0[illegible] = 0.05414 ∠11°23'58''	[illegible].82 ∠90°01'58''	0
50	250	0.02146 + j1.67690 θ_2 = 96°04'58	0.00227 + j0.99460 = 0.99460 ∠89°52'07''	59803 ∠0°07'[illegible]''	0.10598 + j0.02133 = 0.108[illegible] ∠11°22'48'	5.62 ∠90°03'08''	+00.[illegible]2
75	225	0.03220 + j1.73004 θ_2 = 99°07'28	0.0051[illegible] + j0.98785 = 0.98786 ∠89°42'13''	593[illegible]7 ∠0°17'47''	0.[illegible]5836 + j0.0[illegible]9 = 0.16[illegible]31 ∠11°1[illegible]'4[illegible]'	23.37 ∠90°06'08	+00.32
100	200	0.04294 + j1.78313 θ_2 = 102°09'57	0.00905 + j0.97844 = 0.97847 ∠89°28'12''	587[illegible]5 ∠0°31'48''	0.21090 + j0.04[illegible]9 = 0.21503 ∠11°15'35''	31.05 ∠90°[illegible]	+00.[illegible]1
125	175	0.0536[illegible] + j1.83621 θ_2 105°12'26'	0.01409 + j0.96[illegible] = 0.96648 ∠89°09'50''	5803[illegible] ∠0°50'10''	0.26269 + j0.05[illegible] = .26776 ∠11°09'50'	3[illegible] ∠90°16'06''	+00.99
150	150	0.06441 + j1.88930 θ_2 = 108°14'50''	0.02018 + j0.95168 = 0.9[illegible]188 ∠88°4[illegible]'07''	57[illegible]5[illegible] ∠[illegible]°12'53''	0.31[illegible]80 + j0.0[illegible]20 = 0.3[illegible]470 ∠11°02'10''	4[illegible].17 ∠90°23'[illegible]	[illegible].42
175	125	0.07514 + j1.94238 θ_2 = 111°17'25''	0.02731 + j0.93436 = 0.93476 ∠88°[illegible]9'33''	56[illegible]2[illegible] ∠1°40'2[illegible]''	0.36417 + j0.07006 = 0.37085 ∠[illegible]0°53'22''	53.55 ∠90°32'33''	+1.98
200	100	0.08588 + j1.99546 θ_2 = 114°19'54'	0.03543 + j0.91452 = 0.91522 ∠87°46'53''	54955 ∠2°13'07'	0.41354 + j0.07835 = 0.42090 ∠10°43'4[illegible]''	60.[illegible] ∠90°42'[illegible]5''	+2.65
225	75	0.0966[illegible] + j2.04854 θ_2 = 117°22'24	0.04449 + j0.89218 = 0.89328 ∠87°08'43''	53638 ∠2°51'17''	0.46194 + j0.08593 = 0.4[illegible]986 ∠10°32'[illegible]6'	[illegible]7.8[illegible] ∠90°53'40''	+3.40
250	50	0.10735 + j2.10164 θ_2 = 120°24'53'	0.05445 + j0.86735 = 0.86905 ∠86°24'28''	52183 ∠3°35'32''	0.50917 + j0.09275 = 0.51[illegible]55 ∠10°19'26'	74.73 ∠91°06'30''	+4.33
275	25	0.11808 + j2.15473 θ_2 = 123°27'22''	0.06525 + j0.84014 = 0.84267 ∠85°33'33''	50599 ∠4°26'27''	0.55514 + j0.09874 = 0.56385 ∠10°05'07''	81.42 ∠9[illegible]°20'40''	+5.41
300	0	0.12882 + j2.20781 θ_2 = 126°29'52''	0.07683 + j0.81056 = 0.81420 ∠84°35'08''	48889 ∠5°24'52''	0.59973 + j0.10384 = 0.60865 ∠9°49'22''	87.89 ∠91°36'34''	+6.64



SINH $(\theta_1 + j\theta_2)$ $(\text{SINH}\ \theta_1\ \text{COS}\ \theta_2 + j\ \text{COSH}\ \theta_1\ \text{SIN}\ \theta_2)$.

COSH $(\theta_1 + j\theta_2)$ $(\text{COSH}\ \theta_1\ \text{COS}\ \theta_2 + j\ \text{SINH}\ \theta_1\ \text{SIN}\ \theta_2)$.

ANGLE AT RECEIVING END θ_{RO} = 0 + j 1.57080

ANGLE OF LINE θ = 0.12882 + j 0.63701

$\theta_{SO} = \theta + \theta_{RO}$ = 0.12882 + j 2.20781

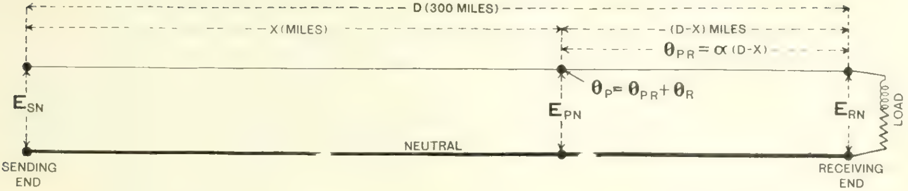
ONE QUADRANT 1.5707[illegible] CIRCULAR RADIANS

ONE CIRCULAR RADIAN=206264,8062''=57°17'44.8''

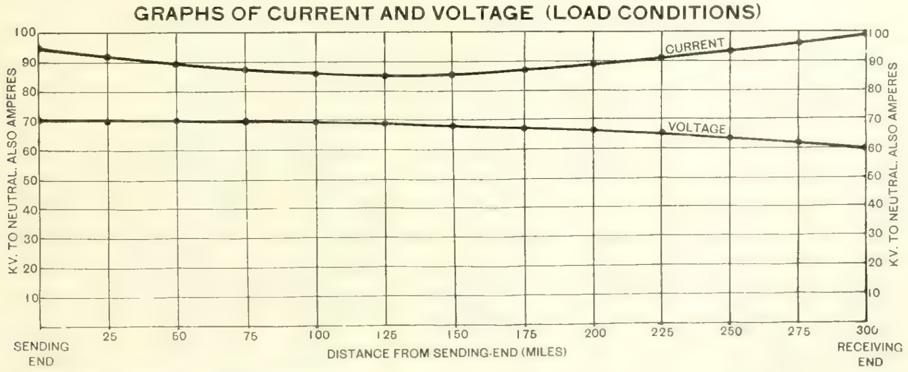
α -0.00042939 + j 0.00212336

FIG. 50—CURRENT AND VOLTAGE DISTRIBUTION

For problem *X* by position angles (zero load conditions).



(D-X) MILES	X MILES	POSITION ANGLE $\theta_P = \theta_{PR} + \theta_R$	SINH θ_P (THE VOLTAGE FOLLOWS THIS COMPLEX FUNCTION)	E_{PN} VOLTS $\angle$	COSH θ_P (THE CURRENT FOLLOWS THIS COMPLEX FUNCTION)	I_P AMPERES $\angle$	PF_P %
0	300	$0.48047 + j1.06354$ $\theta_2 = 60^\circ 56' 11''$	$0.24249 + j0.97693$ $= 1.00657 \angle 76^\circ 03' 35''$	60 046 $\angle 0^\circ 0' 0''$	$0.54294 + j0.43632$ $= 0.69654 \angle 38^\circ 47' 10''$	99.92 $\backslash 25^\circ 50' 31''$	−90.00
25	275	$0.49120 + j1.11662$ $\theta_2 = 63^\circ 58' 40''$	$0.22426 + j1.0092$ $= 1.0338 \angle 77^\circ 28' 16''$	61 670 $\angle 1^\circ 24' 41''$	$0.49272 + j0.45937$ $= 0.67364 \angle 42^\circ 59' 38''$	96.64 $\backslash 21^\circ 38' 03''$	−93.83
50	250	$0.50194 + j1.16971$ $\theta_2 = 67^\circ 01' 10''$	$0.20430 + j1.0391$ $= 1.0590 \angle 78^\circ 52' 36''$	63 173 $\angle 2^\circ 49' 01''$	$0.44064 + j0.48176$ $= 0.65288 \angle 47^\circ 33' 08''$	93.66 $\backslash 17^\circ 04' 33''$	−94.04
75	225	$0.51267 + j1.22279$ $\theta_2 = 70^\circ 03' 39''$	$0.18259 + j1.0663$ $= 1.0819 \angle 80^\circ 16' 59''$	64 540 $\angle 4^\circ 13' 24''$	$0.38682 + j0.50333$ $= 0.63480 \angle 52^\circ 27' 25''$	91.06 $\backslash 12^\circ 10' 20''$	−95.94
100	200	$0.52341 + j1.27587$ $\theta_2 = 73^\circ 06' 09''$	$0.15917 + j1.0909$ $= 1.1025 \angle 81^\circ 41' 55''$	65 770 $\angle 5^\circ 38' 20''$	$0.33139 + j0.52399$ $= 0.61999 \angle 57^\circ 41' 22''$	88.94 $\backslash 6^\circ 56' 19''$	−97.60
125	175	$0.53414 + j1.32895$ $\theta_2 = 76^\circ 08' 38''$	$0.13409 + j1.1127$ $= 1.1207 \angle 83^\circ 07' 43''$	66 854 $\angle 7^\circ 04' 08''$	$0.27447 + j0.54361$ $= 0.60815 \angle 63^\circ 12' 39''$	87.24 $\backslash 1^\circ 25' 02''$	−98.90
150	150	$0.54488 + j1.38204$ $\theta_2 = 79^\circ 11' 07''$	$0.10735 + j1.1317$ $= 1.1368 \angle 84^\circ 34' 52''$	67 815 $\angle 8^\circ 31' 17''$	$0.21618 + j0\ 56197$ $= 0.60211 \angle 68^\circ 57' 32''$	86.37 $\angle 4^\circ 19' 51''$	−99.73
175	125	$0.55561 + j1.43512$ $\theta_2 = 82^\circ 13' 36''$	$0.07908 + j1.1477$ $= 1.1504 \angle 86^\circ 03' 30''$	68 626 $\angle 9^\circ 59' 55''$	$0.15667 + j0.57927$ $= 0.60080 \angle 74^\circ 51' 57''$	86.34 $\angle 10^\circ 14' 16''$	+99.99
200	100	$0.56635 + j1.48821$ $\theta_2 = 85^\circ 16' 05''$	$0.04926 + j1.1607$ $= 1.1618 \angle 87^\circ 34' 11''$	69 306 $\angle 11^\circ 30' 36''$	$0.09608 + j0.59508$ $= 0.60279 \angle 80^\circ 49' 42''$	86.47 $\angle 16^\circ 12' 01''$	+99.66
225	75	$0.57708 + j1.54129$ $\theta_2 = 88^\circ 18' 35''$	$0.01798 + j1.1707$ $= 1.1708 \angle 89^\circ 07' 13''$	69 843 $\angle 13^\circ 03' 38''$	$0.03455 + j0.60939$ $= 0.60962 \angle 86^\circ 45' 18''$	87.45 $\angle 22^\circ 07' 39''$	+98.75
250	50	$0.58782 + j1.59438$ $\theta_2 = 91^\circ 21' 04''$	$-0.01471 + j1.1775$ $= 1.1775 \angle 90^\circ 42' 57''$	70 243 $\angle 14^\circ 39' 22''$	$-0.02784 + j0.62207$ $= 0.62270 \angle 92^\circ 33' 44''$	89.33 $\angle 27^\circ 56' 03''$	+97.32
275	25	$0.59855 + j1.64746$ $\theta_2 = 94^\circ 23' 34''$	$-0.04863 + j1.1811$ $= 1.1821 \angle 92^\circ 21' 28''$	70 517 $\angle 16^\circ 17' 53''$	$-0.09073 + j0.63306$ $= 0.63953 \angle 98^\circ 09' 22''$	91.74 $\angle 34^\circ 11' 41''$	+95.17
300	0	$0.60929 + j1.70055$ $\theta_2 = 97^\circ 26' 03''$	$-0.08381 + j1.1814$ $= 1.1844 \angle 94^\circ 03' 28''$	70 652 $\angle 17^\circ 59' 53''$	$-0.15416 + j0.64226$ $= 0.66050 \angle 103^\circ 29' 45''$	94.75 $\angle 38^\circ 52' 04''$	+93.43



$\text{SINH}(\theta_1 + j\theta_2) = (\text{SINH}\,\theta_1 \text{ COS}\,\theta_2 + j \text{ COSH}\,\theta_1 \text{ SIN}\,\theta_2).$

$\text{COSH}(\theta_1 + j\theta_2) = (\text{COSH}\,\theta_1 \text{ COS}\,\theta_2 + j \text{ SINH}\,\theta_1 \text{ SIN}\,\theta_2).$

ANGLE AT RECEIVING END $\theta_R = 0.48047 + \ 1.06354$
ANGLE OF LINE $\theta = 0.12882 + \ 0.63701$
$\theta_S = \theta + \theta_R = 0\ 60929 + \ 1\ 7005$

ONE QUADRANT=1.57079632 CIRCULAR RADIANS.
ONE CIRCULAR RADIAN=206264.8062″=57° 17′ 44.8″

$\alpha = 0.00042939 + j\,0.00212336$

FIG. 51 CURRENT AND VOLTAGE DISTRIBUTION
For problem X by position angles (load conditions).

any point on the line is the perpendicular sum of the separate frequency values.

A detail discussion of the manner of including the effect of harmonic components in the current and voltage waves is quoted below from Dr. Kennelly's "Artificial Electric Lines."

"The ordinary complex harmonic impressed e.m.f. contains a fundamental frequency associated with multiple frequency harmonics. The *n*th multiple of the frequency is called the *n*th harmonic. The fundamental may thus be included as the first harmonic.

"In order to deal with the plural-frequency case quantitatively, it is necessary to analyze the impressed potential wave into its harmonic components. As is well known, the complete Fourier analysis of a complex wave may be written

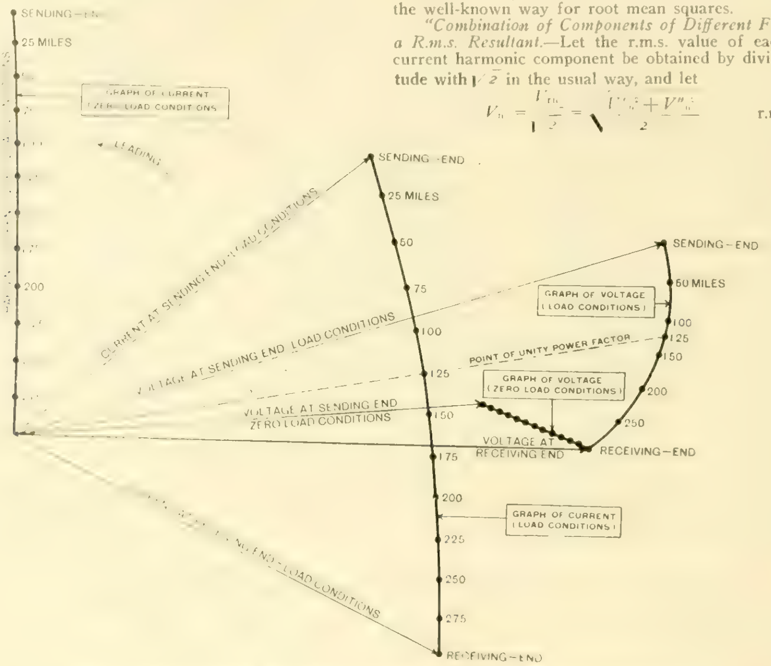

SENDING–END
25 MILES
GRAPH OF CURRENT (ZERO LOAD CONDITIONS)
LEADING
200
SENDING–END
25 MILES
50
75
100
125
150
175
200
225
250
275
RECEIVING–END
CURRENT AT SENDING END NO LOAD CONDITIONS
VOLTAGE AT SENDING END LOAD CONDITIONS
VOLTAGE AT SENDING END ZERO LOAD CONDITIONS
SENDING–END
50 MILES
GRAPH OF VOLTAGE (LOAD CONDITIONS)
100
125
150
POINT OF UNITY POWER FACTOR
GRAPH OF VOLTAGE (ZERO LOAD CONDITIONS)
200
250
VOLTAGE AT RECEIVING END
RECEIVING–END
GRAPH OF CURRENT (LOAD CONDITIONS)
SENDING END LOAD CONDITIONS

FIG. 52—POLAR DIAGRAM OF CURRENT AND VOLTAGE DISTRIBUTION FOR PROBLEM X

$$V = V_0 + V'_1 \sin \omega t + V'_2 \sin 2\omega t + V'_3 \sin 3\omega t + V'_4 \sin 4\omega t + V''_1 \cos \omega t + V''_2 \cos 2\omega t + V''_3 \cos 3\omega t + V''_4 \cos 4\omega t + \dots \dots \text{ volts} \quad (1)$$

where V_0 is a continuous potential, such as might be developed by a storage battery, ordinarily absent in an a. c. generator wave, V'_1, V''_1, V'_2, V''_2, etc., maximum cyclic amplitudes of the various sine and cosine components. The even harmonics are ordinarily negligible in an a. c. generator wave; so that V'_2, V''_2, V'_4, V''_4, etc., are ordinarily all zeros. If we count time from some moment when the fundamental component passes through zero in the positive direction, $V''_1 = 0$ and the [illegible]

$$V = V'_1 \sin \omega t + [illegible] \sin 3\omega t + \dots + V''_3 \cos 3\omega t + \dots \text{ volts} \quad (2)$$

Compounding sine and cosine harmonic components into resultant harmonics of displaced phase, this may be expressed as

$$V = V_1 \sin (\omega t + \beta_1) + V_3 \sin (3\omega t + \beta_3) + \dots \text{ volts} \quad (3)$$

where $V_n = \sqrt{V'^2_n + V''^2_n}$ volts (4)

and $\tan \beta_n = \frac{V''_n}{V'_n}$ numeric (5)

[illegible] (1) or (2) gives the wave analysis in *sine and cosine harmonics*, while (3) gives it in *resultant sine harmonics*.

"When considering a plural-frequency alternating-current line, we require to know the harmonic analysis of the impressed potential, either in sine and cosine harmonics, or in resultant harmonics, the latter analysis is preferable, as being shorter and containing fewer terms. A decision must be made as to the number of frequencies or upper harmonics which must be taken into account.

"Ordinarily, the sizes of the harmonics diminish as their order increases; but there are numerous exceptions to this rule, as when some particular tooth frequency in the alternating-current generator establishes a prominent size for that harmonic. Care must therefore be exercised not to exclude any important harmonics. On the other hand, the fewer the harmonics to be dealt with, the better, because the labor involved in correctly solving the problem increases in nearly the same ratio as the number of harmonics retained.

"The rule is to work out the position angle, r.m.s. potential, and r.m.s. current distributions, over the artificial or conjugate smooth line, for each harmonic component in turn, as though it existed alone, and then to combine them, at each position, in the well-known way for root mean squares.

"*Combination of Components of Different Frequencies into a R.m.s. Resultant.*—Let the r.m.s. value of each alternating-current harmonic component be obtained by dividing its amplitude with $\sqrt{2}$ in the usual way, and let

$$V_n = \frac{V_{mn}}{\sqrt{2}} = \sqrt{\frac{V'^2_n + V''^2_n}{2}} \quad \text{r.m.s. volts} \quad (6)$$

be the r.m.s. value of the *n*th harmonic. Then the r.m.s. value of all the harmonics together, over any considerable number of cycles, will be

$$V = \sqrt{V_1^2 + V_2^2 + V_3^2 + \dots\dots\dots} \quad \text{r.m.s. volts} \quad (7)$$

or, as is well known, the joint r.m.s. value of a plurality of r.m.s. values of different frequency, is the square root of the sum of their squares. If a continuous potential V_0 be present, this may be regarded as a r.m.s. harmonic of zero frequency, and be included thus:

$$V = \sqrt{V_0^2 + V_1^2 + V_2^2 + V_3^2 + \dots} \text{ r.m.s. volts} \quad (8)$$

Moreover, from (4), it is evident that the squares of the r.m.s. values of the sine and cosine terms of any harmonic may be substituted for the square of their resultant; or that, in this respect, the sine and cosine terms may be treated as though they were components of different frequencies.

"The same procedure applies to plural-frequency currents. Find the r.m.s. resultant harmonics. The r.m.s. value of all together will be the square root of the sum of their squares. A continuous current, if present, may be included, as the r.m.s. value of an alternating current of zero frequency.

"*Graphical Representation of R.m.s. Plural-frequency Combination.*—The process represented algebraically in (7) or (8) may be represented graphically by the process of successive perpendicular summation, or "crab addition." An example will suffice to make this clear. A fundamental alternating current of 100 amp. r.m.s., is associated with a continuous current of 50 amp., and with two other alternating currents of other frequencies of 20 and 10 amp. r.m.s., respectively. What will be the joint r.m.s. current? Here by (8),

$$I = \sqrt{100^2 + 50^2 + 20^2 + 10^2} = \sqrt{10\,000 + 2500 + 400 + 100}$$
$$= \sqrt{13\,000} = 114.0175 \text{ amp. r.m.s.}$$

"In Fig. 53, *OA* represents the fundamental r.m.s. current. *AB*, added perpendicularly to *OA* represents the continuous current, or current of 50 r.m.s. amp. at zero frequency. The perpendicular sum of *OA* and *AB* is *OB* = 111.8034 amp. Adding similarly the other frequency components *BC* and *CD*, the total perpendicular sum is *OD* = 114.0175 amp. The order in which the components are added manifestly does not affect the final result, and it is a matter of insignificance whether the various frequencies coacting are "harmonic," *i. e.*, are integral multiples of a fundamental, or not, so long as they are different.

"The complete solution of an alternating-current line with complex harmonic potentials and currents thus requires an independent solution of potential and current for each single frequency in turn, as though the others were non-existent, and then the r.m.s. value at any point on the line is the perpendicular sum of the separate frequency values. The powers and energies of the different frequencies are independent of each other, and the total transmitted energy is the sum of the energies transmitted at the separate component frequencies."

CHOICE OF VARIOUS METHODS

Two graphical and two mathematical forms of solution for circuits of long electrical length have been described thus far. These four methods have been given for the purpose of providing a choice of procedure for the beginner. Graphical solutions are more simple and more readily performed than mathematical solutions and, if used correctly and made to a large scale, will yield results well within the limits of permissible error for power transmission circuits. There is always a possibility of error with any method, even though the solution is carefully checked. For this reason it is desirable that errors be guarded against by the use of two different forms of solution. For instance the first solution could be made by making use of the Wilkinson charts followed by its accompanying graphical solution. The second solution could then be made by means of Dr. Kennelly's ratio charts XVIII to XXI, followed by its accompanying graphical solution. These two methods would then yield results obtained by two entirely different routes and methods of procedure. The use of two such methods would constitute check against errors being made in either solution.

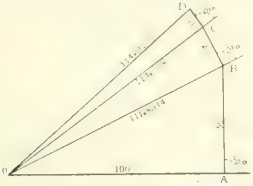


FIG. 53 GEOMETRICAL REPRESENTATION OF A JOINT R.M.S. VALUE OF PLURAL-FREQUENCY COMPONENTS BY PERPENDICULAR SUMMATION OR "CRAB ADDITION"

BIBLIOGRAPHY

In order to give due prominence to some of the valuable contributions on the subject of performance of electrical circuits and as an acknowledgment to their authors of the assistance received from a study of them, the following publications are suggested as representing a very helpful and valuable addition to the library of the transmission engineer. They are given in the approximate order of their publication:—

Calculation of the High Tension Line and Output and Regulation in Long Distance Lines by Percy H. Thomas. (Published in *A. I. of E. E. Trans.* Vol. XXVIII, Part, 1, 1909). The former paper introduces a so-called "wave formula" for determining the performance of long lines having considerable capacity which embodies the use of algebra only. The second paper suggests the use of split conductors in order to adjust the ratio of the capacity and inductance of the line so that the leading and lagging components more nearly neutralize each other.

Formulae, Constants and Hyperbolic Constants by W. E. Miller. (Published in *G. E. Review,* supplement dated May 1910). This is a treatise upon the subject wherein hyperbolic functions of complex angles are tabulated for sinh and cosh $(x + jy)$ up to $x = 1$, $y = 1$ in steps of 0.02.

Transmission Line Formulas by H. B. Dwight. (Published by John Wiley & Sons, Inc.). This book introduces what are known as "Dwight's *'K'* formulas," which permit the solution of transmission problems without the use of mathematics higher than arithmetic. It also contains working formulas based upon convergent series and the solution of many problems both by the *K* formulas and by convergent series.

Tables of Complex Hyperbolic and Circular Functions by Dr. A. E. Kennelly. (Published by the Harvard University Press). This book gives functions of complex angles for polar values up to 3.0 by steps of 0.1 and for angles from 45° to 90° by steps of one degree; also functions in terms of reactangular coordinates $x + jy$ to $x = 10$ by steps of 0.05 and of y virtually to infinity by steps of 0.05.

Chart Atlas of Complex Hyperbolic and Circular Functions by Dr. A. E. Kennelly. (Published by Harvard University Press in large charts, 48 by 48 cm.) Presenting curves for all the tables published in above referred to "Tables of Complex Hyperbolic and Circular Functions" for rapid graphical interpolation.

Constant Voltage Transmission by H. B. Dwight. (Published by John Wiley & Son, Inc.). Embraces a very complete study of the use of over-excited synchronous motors for controlling the voltage of transmission.

The Application of Hyperbolic Functions to Electrical Engineering Problems by Dr. A. E. Kennelly. (Published by the McGraw-Hill Book Company). Every student should have a copy of this book because of its simplicity and completeness in explaining the application of hyperbolic functions to transmission circuit problems. It also contains a very complete bibliography of publications upon this general subject.

Artificial Electric Lines by Dr. A. E. Kennelly. (Published by McGraw-Hill Book Co.). This is a valuable treatise in which the subject is treated in accordance with the hyperbolic theory.

Electrical Phenomena in Parallel Conductors by Dr. F. E. Pernot. (Published by John Wiley & Son, Inc.). Being a very recent treatise, this book contains much practical and many readily understandable explanations for both the beginner and those further advanced in the study of this subject. It contains a six-place table of logarithms of real hyperbolic functions for values of [illegible] intervals of 0.001 in the argument. This is the most complete table of real hyperbolic functions which the author has seen.

Ventilation and Temperature Problems

In Large Turbogenerators

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Chief Engineer,
Westinghouse Electric & Mfg. Company

THERE ARE FOUR EFFECTIVE MATERIALS concerned in turbogenerator operation,—iron for magnetic purposes, copper in the windings, insulation encasing the winding and the ventilating air. The iron and copper have already been carried up to their practical limits, so that the major part of recent developments have been in the insulation and in the ventilation. The physical limitations of the materials having been reached in many ways, it is no longer possible to increase the physical dimensions, as has been the case in lower speed machines.

As insulations have been utilized fairly well up to their limits for some years, the more recent developments have been largely along lines of improved methods of heat dissipation which is largely the problem of air circulation. Broadly, there is but one method in use today, namely forcing a large quantity of air through the machine at a high velocity. The air-forcing means consists of powerful fans or blowers driven either by separate motors, or by the rotor shaft of the turbo alternator itself. The problem is to supply sufficient air to take up the heat generated. It is in the design of the cooling channels or paths that much of the modern turbo-alternator engineering has been expended.

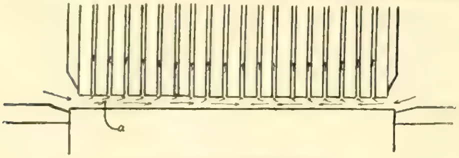

FIG. I—RADIAL VENTILATION
Air passing outward through radial ducts.

The types of ventilating channels may be classified broadly as *radial* and *axial*. Very few machines use either one exclusively. In axial ventilation the air travels in the general direction of the shaft, whereas in the radial arrangement the movement is at right angle to the shaft. The air-gap ventilation in the turbogenerator is axial in most cases, while the internal ventilation of the rotor body or core is usually the axial and radial combined. In the same way the ventilation of the stator core is usually a combination of the axial and the radial; for, even in the so-called radial types, the cooling air through the gap passes axially over the armature bore, before passing out radially. In the same way, in the so-called axial types, the air through the axial core channels passes radially out at the core center.

In addition to the purely axial and radial arrangements, there is circumferential ventilation, or air circulation around the machine circumferentially. This has been used in European machines and, in combination with axial and radial arrangements, it appears in certain American types. In fact, in the axial air-gap ventilation, the circumferential action also occurs naturally, due to the speed of the rotor, the air traveling in a spiral path from the ends toward the center of the machine.

RADIAL VENTILATION

In the usual radial ventilation, the air enters the air-gap at each end of the core and, as it travels toward the center, is deflected outward at intervals through the radial ducts. As part of the air passes out through the first and succeeding radial ducts, the volume of air in the gap decreases, thus successively lessening the pressure required to overcome the gap resistance. Thus, there is fairly high pressure at *a*, Fig. 1, and this tends to shunt part of the air out through the radial ducts over *a*.

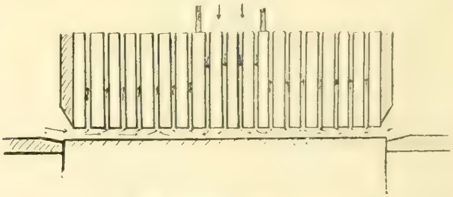

FIG. 2—RADIAL VENTILATION
Air entering and leaving stator through radial ducts

At the center of the machine, due to the velocity of the ingoing air, there is "banking up" of the air, with corresponding pressure tending to drive it out radially. Here the velocity is converted into static pressure. Obviously, the air flow in the different ducts, being due to different conditions of pressure, may be quite unequal. The real problem, therefore, is to obtain proper air flow through the various ducts.

An extension of this problem is found where the width of the core is greater than the permissible air flow can cool. Assume, for instance, with the largest permissible gap the design will allow and the largest allowable diameter of rotor, that a core width of 80 inches can be ventilated by air from the two ends. Now what can be done in case of a core width of 100 or 120 inches, which would be required for a 25 or 50 percent larger output? One answer would be that it is impossible to use cores of such width. But that would put a stop to a certain trend of development and, therefore, some solution involving an important modification must be adopted. One of these is to put air in, radially, at the middle part of the stator core, and to allow it to

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NOTE—Based on a paper read before The American Institute of Electrical Engineers, June, 1920.

flow axially *toward the ends,* in the air-gap and then out radially, as shown in Fig. 2. Here the entering air must be forced in against the rotation of the rotor core, and possibly against the velocity effects of the air from the end gaps. In consequence the pressure may have to be considerably different from that for forcing the air in at the end gaps. Nevertheless this general arrangement has been used with considerable success.

The above description of the difficulties of the problem has been given, not as a criticism of this particular arrangement or method, but simply to illustrate some of the difficulties encountered in large turbogenerator design.

AXIAL VENTILATION

As stated before, axial ventilation is usually partly radial. In this method, as usually applied, air not only passes axially along the air-gap and out at radial ducts at the center of the core, but axial ducts, or channels, parallel to the shaft or air-gap, are in the stator core, back of the armature slots, to allow air to flow parallel with the gap. The intention is to force sufficient air through the gap to cool the rotor, and the stator tooth tips, while air through the stator ducts, will further cool the stator teeth and armature core. In the early designs one large central duct was used, this being changed later to two or three narrow ones, while in the latest types, there may be a dozen or more radial ducts, taking up a considerable portion of the central zone of the stator. With this latter arrangement, Fig. 3, the central part might be considered as radially ventilated, while the end parts are axially ventilated. The real merits and demerits of this later construction, compared with the so-called radial type can only be judged properly when the quantitative conditions of the problem are taken into account.

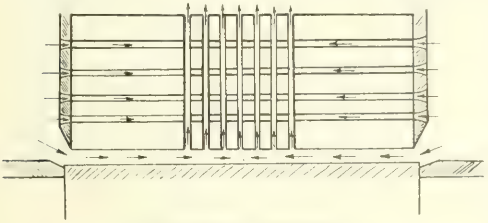


FIG. 3—AXIAL VENTILATION

Air entering stator through air-gap and axial ducts flowing outward through radial ducts.

A variation of the above axial scheme consists in supplying air, under pressure, to the central radiating ducts which then passes through the stator channels and the air-gap, to the two ends. Or, again, the ventilating fan may operate reversed so that it *pulls* the air through from the central ducts. One advantage of the latter arrangement is that the friction loss due to the fan heats the outgoing instead of the ingoing air.

It will be seen that with the axial arrangement, like the radial, the problem is to obtain the best air distribution with a large number of parallel paths and with different resistances of the various paths. One advantage of the axial arrangement is that part of the parallel paths,—those in the stator core—are under possible control at the inlet.

CIRCUMFERENTIAL VENTILATION

This method should be considered, as it has been used commercially to a considerable extent. It is in reality a combination of radial and circumferential methods. As usually applied, there are radial passages through the stator core, but divided circumferentially into groups, so that the air passes inward to the air-gap in certain axial zones, and then circumferentially around the gap to the next zone where it passes out radially, as shown in Fig. 4. At first glance this looks like an ideal arrangement, but a little study will show that it also has its limitations, just like the other methods, for there is no way to insure proper division of the air among the parallel paths. For instance, if one zone covers eight teeth, then due to crowding of the air in the gap, due to the rotor velocity, the pressures might be balanced in some of the tooth passages so that there is practically no air flow in those particular elements. This would mean very unequal temperatures in the tooth belt as a whole, and so the problem thus narrows down to one of proper air distribution, just as in all other arrangements.

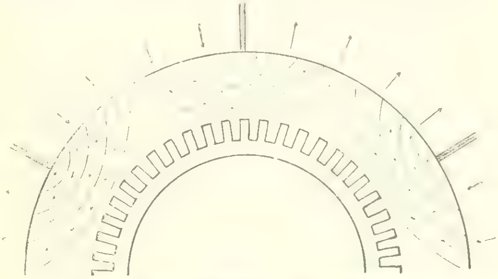
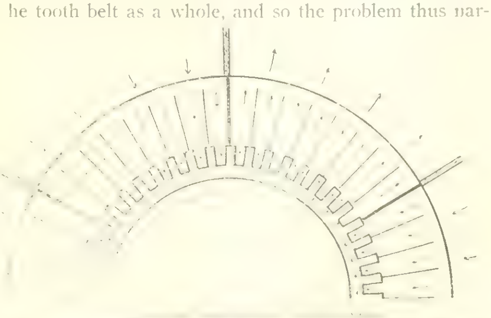


FIG. 4—CIRCUMFERENTIAL VENTILATION

Air flowing circumferentially both with and against the direction of rotor rotation.


Air [illegible] with the [illegible] rotor rotation.

A modification of the above arrangement combines both radial and circumferential methods, Fig. 5. The air from the outer core surface is simply deflected through the stator core, and cools the tooth belt, mainly by conduction through a relatively long path. The stator gap surface and rotor must be cooled by the usual methods.

In addition, there are various other combinations of radial, axial and circumferential methods, each of which possess certain merits.

HEAT FLOW FROM THE ARMATURE COPPER

There are three principal sources of heat, namely, the losses in the copper windings, the iron losses, and the friction of the air at the high velocities used. Considering first the armature windings, all the heat generated must flow through the insulation, the relative rate of flow at any part being dependent principally upon the temperature differences. In addition to the transverse heat flow, through the insulation, there will be a flow along the copper itself from hotter parts toward cooler places. In the end windings, the heat can flow directly from the copper, through the insulation, to the cooling air. Moreover, local or eddy currents in the copper are liable to be least in this part, due to the absence of the iron. Consequently, in the end windings the actual copper temperatures are higher than the surrounding air temperatures only by the amount of temperature drop through the insulation.

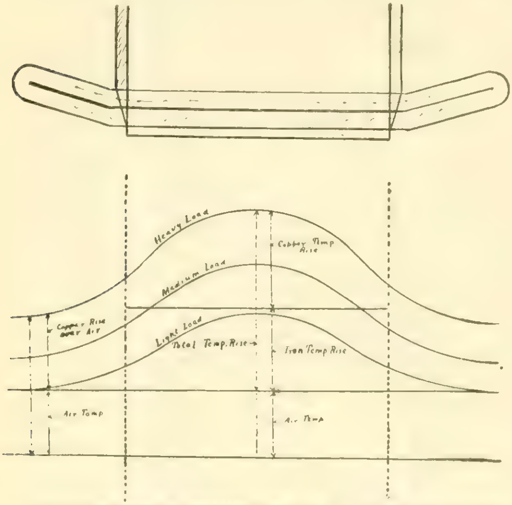


FIG. 6 [illegible]

In the core, however, the conditions are quite different. Here the heat must pass from the copper, through the insulation to the embedding iron, and then through the iron to the cooling surfaces and to the cooling air which may or may not be at as low temperature as that around the end windings. Obviously the temperature of the copper in the buried part will be at a higher temperature than in the end parts. But, as copper is a good heat conductor, this difference in the copper temperature tends to equalize itself by heat flow along the coil itself, thus tending to lower the higher temperature and increase the lower. This action can be quite effective in equalizing the temperatures in the various parts, in those machines where the heat paths are not too long compared with the section of the conducting path and the amount of heat to be conducted. In narrow core machines, with short end windings, the equalization may be within a few degrees, but in the usual wide turbo-generator cores, with the long span end windings, this equalization only shows prominently in the dividing zone between ends and core. In other words there is a very considerable longitudinal heat flow at this part, as illustrated in Fig. 6. Here the temperature of the core with respect to the copper is dependent upon the load conditions. With heavy load this flow may be from the buried copper to the iron at all parts of the core width, while at light load the flow may be from the iron to the copper over the whole core width. At intermediate loads there may be heat flow from the iron to the copper near the ends of the core, and from copper to iron in the mid-portions.

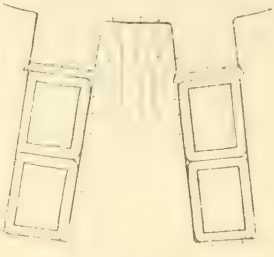
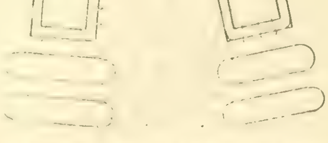


FIG. 7 [illegible]
Improving dissipation of heat.

Considering the heavy load conditions, it is obvious, that in a wide core machine, the center parts should have materially higher temperatures than the end copper, such higher temperatures being due to two or more drops,—(1) through the insulation, (2) through the iron and the surface contact, and (3) to the difference between the cooling air in the core and that around the end windings. This latter effect may be considerable. It should be evident that, if the temperature rise, (or insulation drop, as determined at the end windings, should



[illegible] SLOTS

be 40 degrees C. for instance, then the temperature rise in certain of the embedded parts should be higher by the amount of the adjacent iron temperatures, plus the rise in the cooling air at those parts. If the iron temperature should be 40 degrees above the adjacent cooling air, and the latter should be only 10 degrees above the outer or end air, then this represents 50 degrees additional temperature to be added to the insulation drop from the copper to the iron, or a total of $40^\circ + 50^\circ = 90$ degrees. These should not be taken as representative figures, but are simply assumed, to bring out the general fact. The object is to show that the central portion of the core will necessarily be considerably hotter than the ends, and than an end winding temperature measurement alone is of no value in such apparatus.

HEAT FLOW IN THE ARMATURE IRON

In practically all methods of turbogenerator ventilation there are two general paths of heat flow in the armature iron, namely, along the laminae and transversely. With the radial arrangement of ducts it is usually considered that the heat flow is across the laminations, to the ducts, which is true in certain parts of the core, but is not entirely so in what may be called the *tooth belt*, as distinguished from the body or core back of the teeth. However, it is the tooth belt with which we are mostly concerned, for here are the embedded armature coils. Here the heat flows partly *across* the laminae to the radial duct surfaces, but in many cases quite a large part flows *along* the laminae to some cooler parts, such as the tooth tips, or the core behind the teeth. One reason for the longitudinal flow lies in the much better heat conducting path along the iron, compared with that across the thin laminae with their good coating of insulating (and, therefore, poor heat conducting) varnish.

The flow to the tooth tips is especially large in those cases where the armature coils are sunk some considerable distance below the gap surface, as shown in Fig. 7. Here the tooth tip surface is very materially increased, and the heat dissipation is largely at the edges of the laminations. Experience has shown very considerable improvement in iron temperatures with this sunken coil arrangement.

In the body of the core, back of the slots, the heat flow, in the radial slot arrangement, will be mostly across the laminae. Due to this the ducts should be spaced at quite frequent intervals, there being, usually, one duct for at least each 2 inches of core width. Even with a two inch spacing, temperature differences of as much as 10 degrees may be noted in cases, between the center of the pack and the end laminae.

In the axial arrangement of ducts, the heat flow is largely along the laminations, except at the central part where radial ducts are used. At the tooth tips and air-gap, obviously the heat dissipating conditions are much as in the radial duct arrangement, especially where the coils are well below the surface. There is also a strong flow outward to the core and the axial ducts back of the coil slots, Fig. 8.

From off-hand inspection, Fig. 8, one would say that this method of heat dissipation is less effective than that with radial ducts, as the paths of heat flow are longer. But it is purely a quantitative problem, as the heat flow *across* the laminae is not nearly as effective as along them, possibly in the ratio of 1 to 10, so that the longer path may actually represent considerably less temperature drop than the shorter transverse one. On this basis, it then narrows down to the effective air surfaces for dissipating the heat, and upon the amount of air which can be utilized.

The primary reason for the axial method of ventilation is to get away from some of the physical restrictions of the purely air-gap method of air supply. In the latter method the air supply is through the air-gap, thus limiting the permissible volume of air which can be supplied. The axial arrangement adds core ventilating passages in parallel with the air-gap. Sufficient air is forced through the gap to cool the rotor and also to exert a scouring action on the tooth tips, thus assisting materially in cooling the tooth belt. Additional air is forced through the core ducts, back of the tooth belt, to assist in cooling the teeth and to cool the core proper. As stated before, the effectiveness of the method depends largely upon the duct surface exposed and the quantity of air supplied, just as with other methods of ventilation. The real temperature drops are not so much in the iron itself, as from the exposed surfaces to the air, or the contact drop.

EFFECTS OF HEATING OF THE VENTILATING AIR

As the ventilating air takes up the heat, it rises in temperature and becomes correspondingly less effective as a cooling element. In other words, any addition to the cooling air temperature means a corresponding addition, in degrees, to the temperature of the iron and copper. Therefore, the effectiveness of the air cooling depends to some extent upon the course of the air through the parts to be cooled. Theoretically, if any given part needs the most effective ventilation, then the coolest air should be fed directly to that part, with as little rise as possible. None of the present methods accomplish this completely, but some appear to be more effective than others.

Consider, first, the radial arrangement, where the air enters at each end through the air-gap. The air is heated by friction as it passes along, as about half the total windage loss is in the fan and the other half is in the air passages. Also as the air passes over the rotor and stator gap surfaces, it takes up heat from these parts. In consequence, there is a gradual accession in air temperature, from the ends of the core, towards the center. This adds a corresponding increase to the temperatures of the iron and copper parts. The increase in the air temperature at the central part will be, presumably, about half the total air rise, or possibly more, as the loss due to the air friction in the gap, plus the rotor gap loss, plus the tooth loss dissipated at the air-gap may be taken as equal to, or greater than, the core and tooth losses dissipated directly into the radial ducts.

With auxiliary central duct ventilation (as described in connection with Fig. 2), the rise in the air temperature at the tooth belt, is probably about midway between the temperatures of the entering and exit air. In the axial method, of the more usual type, similar conditions hold, and the temperature rise of the air is somewhat greater at the central parts, than the usual radial arrangement, due to the fact that much the larger part of the heat dissipation to the air occurs by the time the air has reached the central portion. In consequence, the air temperature rise, at the center, is due to the core, as well as the tooth losses, considering only the core channels. In the air-gap the temperature increase of the air is due to air friction and to the stator and rotor gap surface heat dissipation, just as in the radial arrangement. However, it must be borne in mind that the total volume of air through the gap is smaller than in the radial method, which should mean smaller friction loss. Taking into account both the decrease in loss, and the reduced volume of air, the increase in the air temperature in the gap, at the center, may or may not be larger than in the radial arrangement —it is purely a question of proportion.

With the more recent types of axial construction, where the central portion of the stator embodies a large number of radial ducts, the end parts of the core being supplied with axial channels, it is a question whether there is much difference between the axial and radial arrangements, as far as air temperatures are concerned. The above is on the basis of air flowing *towards* what are nominally the hotter parts of the machine. On the basis of the air flow being in the opposite direction, with the axial method of ventilation, there is one important difference. Here the temperature rise of the air is *least* at the central part of the core, and is higher near the ends, whereas the copper temperatures, as shown in Fig. 6, are naturally higher toward the center and lower at the ends, due to longitudinal heat flow from the buried windings toward the ends. The resultant of the two effects is to tend to equalize the copper temperatures in the core, by bringing down the higher points and increasing the lower. There is, however, this advantage in this arrangement, in that there will be higher temperatures in the end windings, so much so that mica end insulation may be required, which usually is not so desirable on the curved end parts. Of course, there are possible remedies for this condition, such as an auxiliary air supply for the ends.

By this reversed axial method, a reduction of the *central* copper temperatures of 10 to 20 degrees might be possible, depending upon the individual designs. However, at some intermediate point *a* in the core there should be no gain, while at the ends there may be an increase of possibly 20 degrees. If the hottest central part, with the usual arrangement, is 10 degrees hotter than the intermediate point *a* of no-temperature-change, then the actual peak or hottest spot temperature of the stator, as a whole, may be materially lowered by this arrangement. The rotor ventilation, however, presents a more difficult problem.

(To be continued)

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

To receive prompt attention a self-addressed, stamped envelope should accompany each query. All data necessary for a complete understanding of the problem should be furnished A personal reply is mailed to each questioner as soon as the necessary information is available; however, as each queston is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply.

[illegible]—Rewinding Induction Motors—I have a 2 hp, 3-phase, 60 cycle, 4-pole, 220 volt, 6.7 amperes per terminal, 1800 r.p.m. type CCL induction motor. I had to rewind this motor which has 30 turns of No. 19 wire in each coil and 48 slots and it is a nice easy motor to wind. I also have to rewind a 2 hp, 3-phase, 4-pole, 60 cycle, 220 volt, 5.6 ampere, 1800 r.p.m., type CS induction motor with 36 slots, and 40 turns of No. 16 wire in each coil. This is the hardest motor to wind that I ever had. Why is it that the CCL motor current is 6.7 amperes and a No. 19 wire carries the current all right and gives good service, while the type CS motor current is 5.6 amperes and it takes a No. 16 wire to carry the current? I have been trying to make it easier to wind this motor by making slight changes in the winding without effecting the operation of the motor in any way; but I would not make any changes without expert advice. I have two changes in mind. The first one is to have 38 turns of No. 16 wire in each coil. I figured that it would then be a 209 volt motor. Did I figure right? I thought this would be entirely satisfactory as most of our motors operate on about 206 to 215 volts. The second change that I figured on was to put 40 turns of No. 17 wire in each coil. If No. 19 wire carries 6.7 amperes on the CCL motor, why won't No. 17 carry 5.6 amperes on the type CS motor?

M.P. (WISC.)

It is impossible to give a specific answer to this question comparing the characteristics of the particular motors mentioned without having all the design data of the two motors available. In general, with two motors of as nearly similar characteristics, the difference in current ratings would indicate that the second motor was a better designed motor, having a higher efficiency and also a higher power-factor, both of which would reduce the current required to produce a given horse-power output. This general statement is corroborated by the fact that the second motor has a larger size of wire and has the same number of series turns per phase as the first motor, which would naturally give it an improved efficiency. There is another consideration which enters into all such comparisons. Motor manufacturers commonly use the same motor frame for a number of different horsepower ratings at different speeds and frequencies in order to reduce the cost by standardized production. It may be possible that the frame and slots of the second motor are a trifle larger than would have been absolutely necessary for a motor of that size. In such a case the size of copper would be selected sufficient to fill the slots completely. Some such requirement may have caused the designer to assign a larger size of wire to the second motor than to the first one. Any motor frame selected in this way may also have a slightly larger core than would have been absolutely necessary, giving a materially improved power-factor. In other words it may be that, for reasons of expediency in manufacturing, the second motor is much more liberally designed than the first one or than other motors of different sizes similar to the second one would have been. It is impossible to state positively that any of the above conjectures correspond to the facts without having all the design data of both motors available. Under the circumstances either one of your suggestions would doubtless prove satisfactory, that is, it would be satisfactory to wind the coils either with 38 turns of No. 16 wire or with 40 turns of No. 17 wire. The latter suggestion would probably give you the more satisfactory all around results. C.R.R.

1900—EFFECTS OF TEMPERATURE ON INSULATION—Is insulation on electrical apparatus weaker when cold than when hot? R.A.B. (MASS.)

In general the effect of increasing temperature on the insulation of electrical apparatus is a lowering of the resistance, increase of the power-factor and a lowering of the breakdown strength. This statement must not be confused with the effect of "curing" insulation by the application of heat which drives off moisture and betters the insulation in the above respects. No exact law can be stated showing the effect of temperature on the above properties which will apply to all the different kinds of insulation. J.E.S.

1901—SHORT-CIRCUITED TURNS IN SERIES FIELD COILS—What is the best way to test series field coils for short-circuited turns if only a voltmeter and ammeter are at hand?. F.H. (W.VA.)

If the voltmeter is a sufficiently low reading one the comparison of the drop across the series turns on each pole with the same current flowing should be made. If these differ radically an investigation will develop where the short-circuit is. This same comparison could be made from one turn to another if these turns are exposed for easy accessibility, such as is the case with the larger direct-current machines and rotary converters. In this case the voltmeter would have to be adapted for reading at a very low voltage. If the current used is of suitable value, the ordinary millivoltmeter would be adaptable for the purpose. E.I.C.

1902—RE QUESTION 1612—Referring to formula given in answer to question 1612 (Winding design) July 1918, please explain: (a) Should the square inches obtained by multiplying the cross section of one tooth by the number of teeth plus the total number of poles be added to the square inches of X-Y-S-W of Fig. 1612 B and used in equation (2)? (b) Is the total number of poles meant to be the number of poles of one phase or all the phases of the machine? (c) Does one turn in a coil equal two or one conductor? (d) Give formula to find number of turns for a frame having these dimensions X-Y 1¾ inch. Y-Z 4 in. thickness at middle point of tooth $\frac{5}{16}$ in. 24 slots desired to have 440 volts, 25 cycle, 1500 r.p.m., 3 phase. (e) After the number of turns are found how is the connection determined as to star or delta, single or parallel? (f) What is the correct way of finding the chord factor of a 72 slot machine, 25 cycle, 1500 r.p.m., if the coils span is 1-21? L.S.B. (OHIO)

The answer to 1612 July 1918 contains a typographical error. In the 8th line below equation (2), the plus sign should be a division sign. The cross sectional area of the teeth per pole equals the cross section of one tooth times the total number of teeth divided by the total number of poles for which the machine is wound. (a) The cross sectional area of the teeth should not be added to the cross sectional area of the frame but each should be considered separately. (b) Each magnetic pole of a three-phase induction motor it set up by three pole-phase groups of the winding. By "total number of poles" is meant the actual number of magnetic poles or one-third the number of pole-phase groups as shown in the winding diagram. (c) One turn equals two conductors. (d) Applying your figures to equation (1) of question 1612 gives for the frame:

$$80\,000 \times 2 \times 1\tfrac{3}{4} \times 4 = \frac{45 \times 10^6 \times 440}{25 \times cond \times 0.05 \times 0.6} \ldots\ldots\ldots (1)$$

for a series delta connected winding. If the winding is to be star connected the volts per leg instead of the phase voltage should be used; that is, in place of 440 use 440 divided by 1.73 = 254. For the slots:

$$80\,000 \times \frac{5}{16} \times 4 \times \frac{24}{2} \times 0.636 = \frac{45 \times 10^6 \times 440}{25 \times cond \times 0.05 \times 0.6} \ldots\ldots\ldots (2)$$

for a delta winding. In both the above questions cond = the total number of conductors in series per phase. Solving equation (1) gives a value of 70 conductors in series per slot for a series star winding or 35 turns per coil, which is about what would be expected for a motor for the dimensions given. It is, of course, impossible for us to check this exactly as you do not state the horse-power of your motor. Solving equation (2) gives for the above number of conductors a value of over 90 000 for the flux density in the teeth, which is a little high, but is probably allowable. But if it is not desired to work the teeth at such a high density, the desired magnetic flux can be inserted in the left hand member of equation (2) (the value of 80 000 given above is a good conservative figure) and the equation solves for the number of conductors which will give without flux density in the teeth. This will require a slightly larger number of conductors per slot. This is more apt to be the case in a slow speed motor of large horse-power. It is usually easier to wind all the turns in a single coil in series, and then, if necessary connect two or more of the coils in parallel. Either a delta or star winding may be used, depending upon which will give the most convenient size of wire, as sometimes by changing the size of wire and number of turns correspondingly, in order to make a delta or star connection, a better space factor can be obtained, that is the wires will fit into the coil more easily. Sometimes by changing from a star to delta connection or by using various parallel combinations, standard coils which have been prepared for a different motor may exactly fit the one you are repairing. Such considerations always enter into the design of the winding. In your particular case, and in general with small motors, it is better to use a star connection in order to reduce the number of turns, which is 1.73 times as much with a delta connection as it is with a star connection. (g) The method of determining the chord factor is given in detail in an article by Mr. A. M. Dudley on "Reconnecting Induction Motors" which was published in the Journal for February, 1916. On page 93 of this article is given an equation which is easy to use and sufficiently accurate for all practical purposes. This equation is:

$$Chord\ Factor = \sqrt{\frac{N^2 - 2n^2}{N^2}}$$

N = number of slots per pole.
n = number of slots dropped.

Substituting your values in this equation gives $Chord\ Factor = \sqrt{\frac{(36)^2 - 2\,(16)^2}{36^2}}$ = 0.778. The exact value for the angle spanned is $\frac{20}{36}$ 180° = 100° and the sine of one-half this angle is 0.766, checking closely with the above approximate equation. A.M.D.

1903—AIR-GAP DESIGN OF TURBO-GENERATOR—Do the large air-gaps used on turbo-alternators bear any relation to the short-circuit current; or are the air-gaps merely made large to keep the density of the air-gap magnetic flux at a suitable value? R.B.G. (MONT.)

It is obvious, from the well known e.m.f. formula, that a definite amount of field flux is required to produce a given e.m.f. in a generator which has a given armature winding. The only effect, under no load, of increasing the radial length of the air-gap is to increase the number of field ampere-turns required to produce the given field flux. In turbo-generators, the radial length of the air-gap is made larger in order:—(a) To improve the voltage regulation of the generator. By making the air-gap large, the no-load field ampere-turns can be made relatively high with respect to the demagnetizing ampere-turns of the armature, and consequently the percentage increase in the field current required from the no-load to full-load conditions can be made smaller. A reduced range in the field current from no-load to full-load gives correspondingly better voltage regulation. (b) To increase the cross-section of the passage for the cooling air. This is especially true for generators having the radial type of ventilation in which all of the cooling air must pass through the air-gap before entering the stator. With other types of ventilation it is also essential to have a large amount of cooling air pass through the air-gap; and (c) To increase the leakage reactance of the generator. With a large air-gap, the leakage flux between the field and armature circuits is increased The larger leakage flux per ampere, reduces the maximum value of the armature current under short-circuit conditions. This latter consideration is, however, not of great importance. C.M.L.

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

JULY 1920

Voltage Testing of Control Equipment

DETERMINATION OF CREEPAGE

In determining the basis for allowable creepage distances, it was necessary to work out empirically a set of curves which would hold good for practically all insulating surface conditions. Obviously, exposed creepage surfaces must be considered at their worst condition, which prevails on railway control apparatus after the equipments have been in service for some time, during which considerable dirt containing carbon and metal dust, has accumulated. The results of a number of tests made on insulating surfaces in all positions, that is, vertical, horizontal top and horizontal inverted, are shown in Fig. 1. The surfaces tested include a wide range of insulating materials under various conditions, such as clean surface, surface coated with non-conducting dirt and surfaces coated with partially conducting dirt or dust.

TESTING VOLTAGES ON NEW APPARATUS

In conjunction with the tests made to determine the proper value of creepage distances as shown, it was necessary to take into consideration the actual test voltages which would be applied when making the final test on the equipment as a whole. According to the A. I. E. E. Standards, certain tests are given for operating voltages up to 600 volts. For all tests above this value and within the limit of railway usage for direct-current work, the test used is two and one quarter times the operating voltage plus 2000 volts. For 600 volts, a satisfactory test would be 3500 volts, alternating-current, when apparatus is new, and is applied for one minute.

TABLE I—TEST VOLTAGES FOR CONTROL APPARATUS

Type of Apparatus	Condition	Between Jaws	Between Jaws & Case	Between Main Fingers	Fingers to Ground	Terminals to Frame	600 Volt Control	100 Volt Control
Circuit Breaker	New	3500	3500					
	Old	2000	2000					
Drum Controllers	New			3500	3500	3500		
	Old			2000	2000	2000		
Switch Groups	New						3500	2500
	Old						1500	1500
Cutout Switches	New				3500			
	Old				2000			

TESTING APPARATUS

Apparatus for obtaining the various test voltages required is usually of the portable type. The testing apparatus is generally known as a "shooting" box and consists of a voltage transformer which is housed in a wooden box mounted on wheels. A knife switch, circuit breaker and pilot lamp also form part of the equipment. The testing leads are usually of high voltage cable encased in a rubber tubing. These leads terminate in copper wire electrodes about 10 inches long against which the operator is protected by bushings and flash guards.

MAKING TESTS ON NEW APPARATUS

The voltage test on 600 volt apparatus is 3500 volts alternating-current for one minute. For 1200 volts, 5000 volts for one minute is used. These voltage tests are applied between all full operating potential points and ground, and across switch jaws where the full operating voltage is liable to exist. On other parts of the apparatus where voltages other than normal voltage occur, the proper voltage tests should be made. The test voltages for the various parts of control apparatuns are given in Table I.

TESTING EQUIPMENTS WHICH HAVE BEEN IN SERVICE

During the past winter, a great many operating companies experienced an epidemic of failures and consequent service delays, due to lack of inspection. In tracing the cause for these failures, it was found that a great many of them were due to gradual breakdown of insulating surfaces between potential points where dirt and dust had collected, and had not been cleaned off. These failures, through accumulated defects, are not usually detected by the average inspector, as they are not visible to the eye as defects until the damage has been done. Most inspections, even the most rigid, are usually superficial inasmuch as the inert parts do not receive attention. Practically all of the inspection time being used to check up the moving parts and terminal connections. The trouble from inactive parts such as cables, finger base supports and terminal boards usually arises from a breakdown of the insulation, due to abrasion or accumulation of dirt. These troubles could practically all be eliminated by means of a systematic voltage test made at definite intervals. This test would show up the weak spots not only in cable insulation, but also on creepage surfaces. It is, of course, unwise and unnecessary to use the same voltage as is used in testing new equipments. Obviously, apparatus which has been in use some time offers less resistance than new clean material. Voltages for testing old apparatus, or that which has been in service for some time, are also given in Table I along with the voltage tests for new apparatus.

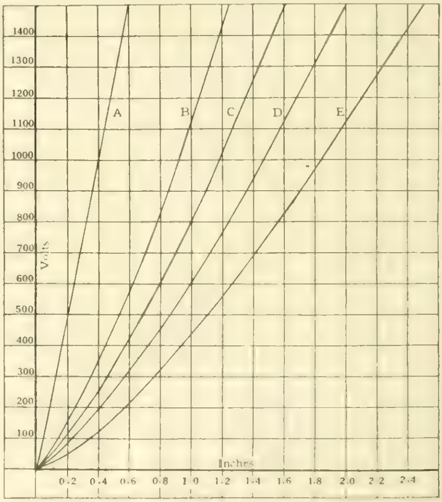


FIG. 1—ALLOWABLE CREEPAGE DISTANCES

A—Air. B—Closed surface or air subjected to gas. C—Exposed surface, inverted. D—Exposed surface, vertical. E—Exposed surface, horizontal.

For determining creepage distances for voltages above 1500 volts. A—Add 0.4 inch per 1000 volts. B—Add 0.64 inch per 1000 volts. C—Add 0.84 inch per 1000 volts. D—Add 1.06 inch per 1000 volts. E—Add 1.36 inch per 1000 volts.

CLEANING OF APPARATUS AFTER TESTING

Although a certain amount of cleaning is done during inspection, it has been found that the right method of cleaning the insulating creepage surfaces has not been employed. When making the voltage tests on creepage surfaces between adjacent potential points, the inspector in charge of such testing can soon determine the weak spots in the insulation. Where these spots occur on creepage surfaces, they should be well cleaned with a gasoline rag to remove grease and dirt, and then should be given a coat of shellac or varnish.

INVESTMENT INVOLVED

In considering the use of a testing outfit and the extra inspection involved, the question of the expense should not be considered too seriously, as the results obtained from intelligent use of voltage tests more than offset the first expense in the prevention of failures. The prevention of failures themselves is not so important as the tieing up of traffic due to these failures.

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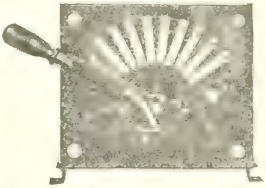

Type P.F. Vitrohm Rheostat
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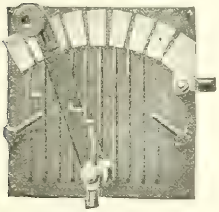
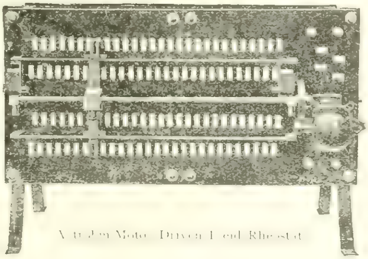


Vitrohm Field Rheostat
for low voltage self-exciting
generator



Vitrohm Motor Driven Field Rheostat

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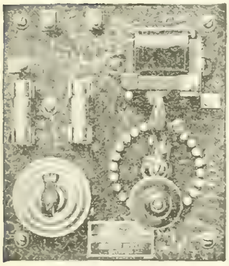

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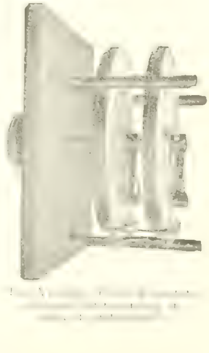

[illegible]

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NATIONAL SAFETY SECTION

SHOP LIGHTING

(Continued)

RECOMMENDED INTENSITY AT WORK, IN FOOT-CANDLES

Roadways and yard thoroughfares	1/10 to ¼
Storage spaces	½ to 1
Stairways, passageways, aisles	1 to 2
Toilets and washrooms	1½ to 3
Rough manufacturing such as rough machining, rough assembling, rough bench work, foundry floor work	2 to 4
Rough manufacturing involving closer discrimination of detail	3 to 6
Fine manufacturing such as fine lathe work, pattern and tool making, light colored textiles	4 to 8
Special cases of fine work, such as watch making, engraving, drafting dark colored textiles	10 to 15
Office work such as accounting, typewriting, etc.	4 to 8

NOTE:—The measurement of illumination should be made at the work with a properly standardized portable photometer or foot-candle meter. This is a simple instrument that anyone can use.

Designing the Lighting System—After determining the intensity required, the items to be considered in designing the lighting system are:—

(a) At what height shall lamps be mounted?

(b) How far apart shall lamps be spaced?

(c) What size of lamp shall be used?

(d) What kind of reflector or globe shall be used?

Height of Lamps—Lamps should be mounted as high as possible unless the ceiling is very high compared to the width of the room, or unless horizontal beams or belting interfere with the light distribution, or unless close spacing is necessary. High mounting permits wider spacing of lamps, with equally good distribution of the light, making it possible to use fewer lamps of larger size, which means lower installation and operating costs. In addition, higher mounting means that nearby lamps are less likely to be within the field of vision of the workers and thus cause eye strain.

Spacing of Lamps—The distance apart that lamps shall be spaced depends upon the character of illumination required. If the work is of an exacting character, close spacings are required to produce the uniform lighting needed, whereas for less exacting purposes wider spacings are permissible. To secure uniform distribution and avoid sharp shadows, the spacing must not be too great in proportion to the mounting height.

DESIRABLE SPACING

Ceiling Height	Fine Work	Rough Work
10 feet	8 to 10 feet	10 to 12½ feet
12 feet	11 to 14 feet	14 to 17 feet
14 feet	13 to 17 feet	17 to 21 feet
16 feet	16 to 20 feet	20 to 25 feet
20 feet	21 to 26 feet	26 to 33 feet
25 feet	27 to 35 feet	35 to 43 feet
30 feet	35 to 45 feet	45 to 56 feet

TYPICAL EXAMPLES

For an Ordinary Metal or Woodworking Shop—14 ft. Ceiling—An intensity of 4 foot candles is desirable. The lamps will be mounted immediately below the ceiling, assuming that they can be so located that belting or other obstructions will not interfere with the distribution of the light. No local lighting will be required. The spacing should be about 17 feet. An intensity of 4 foot-candles will be produced by the use of 150 watt lamps (gas-filled tungsten) spaced 15 feet apart in both directions. The spacing may be varied to suit the location of machines, columns, etc.; for example, the lamps may be spaced 16 feet apart in one direction and 14 feet in the other. If the building construction or the machine layout requires a still different spacing, 200 watt lamps may be used at an average spacing of 18 feet or 100 watt lamps at a spacing of 12 feet—the same intensity being secured in either case. If a 12 foot spacing is used, the lamps should be lowered to about 12 feet above the floor.

For Tool Making, Pattern Making, Light-colored Textile Work—14 ft. Ceiling—An intensity of 8 foot candles is desirable. This class of work requires closer spacing—13 to 17 feet. The 200 watt gas-filled tungsten lamps may be used with 13 foot spacing or 300 watt lamps with 17 foot spacing—depending on the arrangement of machines, columns, etc.

Foundry—The intensity desired at the work is about 4 foot-candles. To allow for loss of light on account of smoke and dust, the lighting should be designed for a theoretical intensity of 6 foot-candles. The mounting height is ordinarily determined by the crane, and the size of lamp will be determined by the height, being approximately as follows:—

20 feet	200 watts
25 feet	300 watts
30 feet	400 watts
35 feet	500 watts
40 feet	750 watts
Over 40 feet	1000 watts

It may be necessary to vary the lamp size slightly to secure a spacing which will conform to the building construction and at the same time secure the desired intensity. Deep-bowl reflectors are generally used. Angle type reflectors are desired where placed along walls below crane runway.

TABLE I—QUALITIES OF REFLECTORS OF DIFFERENT FORMS

	Metal, porcelain-enameled			Glass	
Qualities	Shallow-bowl or dome, 15 degree cut-off angle	Deep-bowl	Shallow-bowl lamp fitted with shield or cap	Deep-bowl mirrored glass	Deep-bowl prismatic glass
Horizontal illumination	Excellent	Fair	Fair	Excellent	Excellent
Vertical illumination	Good	Poor	Poor	Fair	Excellent
Ease of maintenance	Excellent	Excellent	Fair	Fair	Fair
Non-liability to breakage	Excellent	Excellent	Excellent	Fair	Good
Non-liability to deterioration	Excellent	Excellent	Good	Fair	Excellent
Avoidance of eye strain from direct glare	(See Note)	Good	Excellent	Good	Good
Avoidance of glare from polished surfaces	(See Note)	Poor	Excellent	Poor	Poor

Note—The glare from clear lamps is greater with shallow-bowl or dome reflectors than with other types. To prevent excessive glare the lamps should either be frosted or be equipped with opal glass caps, unless mounted at least 20 feet above the floor.

TABLE II—SIZE OF LAMPS AND SPACING REQUIRED FOR VARIOUS INTENSITIES OF ILLUMINATION

The intensities recommended for various operations are given in the text.
L = Lamp size in watts; S = Spacing in feet. (These values do not apply to indirect lighting.)

Foot candles	Vacuum Tungsten		Gas filled tungsten																	
	L	S	L	S	L	S	L	S	L	S	L	S	L	S	L	S	L	S	L	S
¼	50	28	75	39	100	48	150	61	200	72										
½	50	20	75	28	100	34	150	43	200	52	300	66								
1	50	14	75	19	100	24	150	31	200	36	300	47	400	55	500	63				
2	50	10	75	14	100	17	150	22	200	26	300	33	400	39	500	45	750	56	1000	61
3	50	8	75	11	100	14	150	18	200	21	300	27	400	32	500	36	750	46	1000	54
4			75	10	100	12	150	15	200	18	300	24	400	28	500	32	750	40	1000	47
5					100	11	150	14	200	16	300	21	400	25	500	28	750	36	1000	42
6					100	10	150	12½	200	15	300	19	400	23	500	26	750	33	1000	38
8							150	11	200	13	300	17	400	20	500	22	750	28	1000	33
10									200	11	300	15	400	18	500	20	750	25	1000	30
12											300	13½	400	16	500	18	750	23	1000	27
15											300	12	400	14	500	16	750	20	1000	24

THE ELECTRIC JOURNAL

VOL. XVII AUGUST, 1920 NO. 8

The Water Power Bill

The President's signature was affixed to the new Water Power Bill on June 11th last. The Bill passed Congress by good majorities, the House passing it by a vote of 259 to 30, the Senate by 45 to 2. The general feeling throughout the country, and by those interested in our country-wide power development, is that the new law removes most of the previous handicaps which for the past fifteen years have been so discouraging to financial support. Capital could not follow enterprises whose tenure of life was uncertain, where regulations might be made or permits cancelled at the pleasure of a government department, where, indeed, more than one department was sometimes empowered to make vital decisions. It required the stress of war, with its intensified call upon our economic resources, to show us that our earlier laws, intended, of course, to conserve our national resources, were nevertheless having the opposite effect. Water representing millions of kilowatts was running to waste while the supplies of coal and oil were becoming seriously impaired. That is the condition today.

It has been estimated that the potential water power of this country is something like 60 000 000 horse-power, of which 16.6 percent has been developed. About 70 percent of our water power exists in the Pacific and Mountain states, where but 6.5 percent has been developed. Calculations have been made that with maximum storage facilities developed and utilized so as to include seasonal storage, a total capacity of approximately 200 000 000 horse-power might be created. The magnitude of these figures is impressive, when we consider that the steam power used in this country today, exclusive of locomotives, is approximately 25 000 000 horse-power. The country consumes about 600 000 000 tons of coal a year, divided about equally between use for power and use for heating. Its use for power, as every one knows, is very uneconomical. The average efficiency is probably not much better than five percent. Inevitably, we shall come to the zoning of our power districts, where great areas of the country will be served more reliably and more economically by the interconnecting of present systems and the creation of new ones. Steam power will of necessity be largely used. Hydroelectric energy will be employed where possible. It will mean longer distance transmission and higher voltages.

The new Water Power Bill has been quite widely published. It deserves careful reading. It probably is not perfect, but it is hopefully regarded by all informed and thinking men who have realized the momentous need of a change in the laws that would permit of saving these enormous quantities of energy that are now going to waste. These great developments involve not alone the benefits of cheap power. Other great advantages accrue, each in itself large enough to warrant the thought which the subject has had. Much will be accomplished in flood prevention. Large areas of arid low lands may be irrigated with the water coming from the generating plants. Thousands of miles can be added to navigation in our upper rivers and streams. Altogether, this Bill is probably destined to prove a great work of constructive legislation.

E. H. Sniffin,

Modern Testing Equipment

Much emphasis has been placed, and rightly placed, upon designing electrical apparatus so that its user, whether in the home or in the factory, could not by any possible accident come into contact with a live circuit. In certain classes of work, however, which are performed only by trained and experienced electrical experts—notably in the testing of electrical apparatus—it has been too frequently assumed that the operator was sufficiently familiar with the danger of touching a high-potential circuit to protect himself from accidental contact with an unguarded wire or piece of apparatus. This assumption is seldom warranted. The most skillful operator is apt to become careless from long continued familiarity with high-potential apparatus. There are also times when any tester is working below his normal efficiency. Even under the best circumstances, when live parts are unprotected, an individual must spend in avoiding danger, a certain part of his attention and effort which might better be employed in productive work. Moreover, where all possibility of accidental contact is eliminated, much routine electrical testing can be performed by inexperienced men.

With these ideas in mind, the "safety first" test equipment described in this issue by Mr. Heckman has been constructed and has been successfully operated for some time. With this equipment there would seem to be no possible combination of carelessness or deliberate foolishness which will produce a serious accident, as any departure from the normal test methods will immediately open the circuit breakers and disconnect the high potential from all parts of the board and of the apparatus under test. Moreover these safety devices are so arranged as not to interfere in any way with routine testing. In fact the very elements which insure the safety of the operator serve also to make the normal operation quicker and easier. It must be admitted that in certain few cases it is practically impossible to provide protection for all live parts, but every effort should be made in that direction before permitting a man to assume such a grave responsibility as his personal safety.

Chas. R. Riker

Copper—A Delicate Material

N. B. PILLING
Westinghouse Research Laboratory

THE RELIABILITY and strength of the metals used for structural purposes is often times—perhaps too often—taken for granted, and we regard them callously as proof against and unaffected by the barbarous treatment of which they are so often the recipients in manufacturing processes. On second thought, we remember the response of steel, especially certain alloy steels, to heat treatments, an overdose of which may well-nigh prove fatal; the cracking and failure from obscure causes of many brasses; the decay of aluminum and some of its alloys when exposed to certain corroding atmospheres.

Copper, inert in many respects, is not immune, but is subject to a disease of its own, peculiarly insidious and dangerous in the manner of its contraction and its lack of visible symptoms or danger signals. Certain gases, chemically reducing in nature, which may be present in incompletely burned furnace atmospheres or in flames, if permitted to come into contact with heated copper, exert a most baneful effect on the strength and ductility of the latter, an effect all the more serious in that there is no restorative. Of two bars of copper, similarly treated, one may be as strong and tough as could be desired, and the other, identical with the first in outward appearance, may yet be so weak and friable as to be broken without difficulty by the fingers.

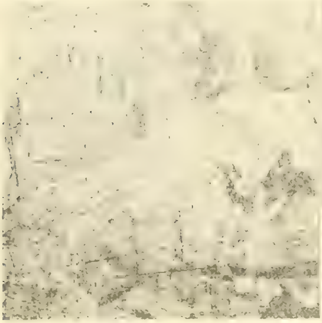
FIG. 1—SECTION THROUGH COPPER SHEET
Showing oxide inclusions, etched. × 75.

FIG. 2—SECTION THROUGH COPPER SHEET
Containing 0.21 percent oxygen. Not etched. × 100.

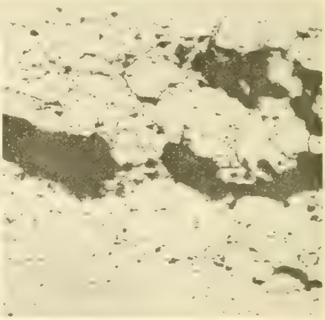
FIG. 3—SPECIMEN SHOWN IN FIG. 2
After 30 minutes heating in hydrogen at 800 degrees C. Not etched. × 100.

In order to understand the cause of this action and ways of combatting it, it is necessary to examine closely the physical make-up of copper and some properties of certain reducing gases.

High grade copper, as used for electrical purposes, is not pure copper. A number of impurities are always present, usually hardly more than traces, with one exception, and that is oxygen. This normally occurs in from 0.03 to 0.08 percent, and is metallurgically necessary during refining to eliminate other more pernicious impurities and to permit the casting of a mechanically sound ingot fit for working. This oxygen is combined as a sub-oxide of copper, and in wrought copper—rod, wire or sheet,—after the succession of mechanical working and annealing treatments, is present as a multitude of finely divided and uniformly scattered particles embedded in the copper. These may readily be seen with a microscope after suitable preparation. Fig. 1 is illustrative. The irregularly shaped areas are the outlines of the crystalline grains of which pure metals are constituted, and indiscriminately scattered throughout are small round oxide particles. In short, "copper" is a mixture of metallic copper and bits of copper oxide.

Certain gases have the property of dissolving in solids at high temperatures and, of these, hydrogen is by far the most active. Cold, it will dissolve in metallic palladium, and an extension of this same manifestation is its ability of dissolving in heated copper. As this dissolved hydrogen penetrates the copper inward from the surface, each granule of copper oxide it meets is attacked and reduced to metallic copper, with the formation of another gas—steam—which is relatively insoluble in copper. The result of this chemical reaction going on at a myriad of isolated points is highly interesting, but hard on the copper. The hydrogen can get in and the steam cannot get out; accumulating at constantly increasing pressure around each of the oxide granules, eventually the cohesive strength of the metal is exceeded and the grains split apart, allowing the steam to escape. An instructive example is shown in Figs. 2 and 3, which are micrographs respectively of a copper sheet containing considerably more oxygen than usual, before and after heating in hydrogen at 800° C. The fissures and cavities have developed without the application of external forces. In Fig. 4 are adjacent sections of a specially prepared, highly oxygenated rod shown before and after heating at 850° C in hydrogen, giving striking evidence of the intensity of the latent forces which may be called into action by a gentle flame playing over the surface.

This action is not peculiar to hydrogen alone; other reducing gases, for example carbon monoxide, will behave similarly but with less violence. The incompletely burned gases in the discharge from a furnace are a complex mixture, but practically hydrogen is the active component, and an examination of the behavior of hydrogen in this respect is sufficient to characterize the action.

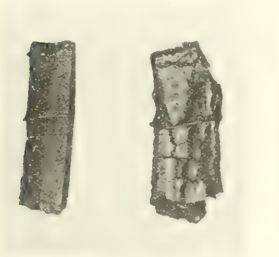

FIG. 4—COPPER ROD CONTAINING 0.50 PERCENT OXYGEN
Before and after heating in hydrogen at 850 degrees C. Natural size.

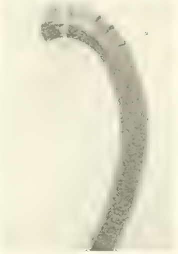

FIG. 5—COPPER ROD DAMAGED BY REDUCING GASES DURING ANNEALING
× 0.6.

The physical effect of hydrogenation is so marked that a simple bending test is sufficient (in cases where it can be applied) for its detection. The effect of annealing temperature upon bending resistance of some 0.625 by 0.048 inch copper strips (0.05 percent oxygen) after a half hour's heating in hydrogen is shown in Fig. 6. Above 400° C a rapid deterioration sets in, which is so pronounced above 700° C that the strip could be broken on the first bend. No such effect followed annealing at similar temperatures in an oxidizing atmosphere, the high bending resistance being unimpaired. It is instructive to compare this curve with Fig. 7, giving the results of some determinations of the velocity of penetration of hydrogen into copper, which could first be detected in the same temperature range (400-500° C) in which incipient deterioration in strength was found.

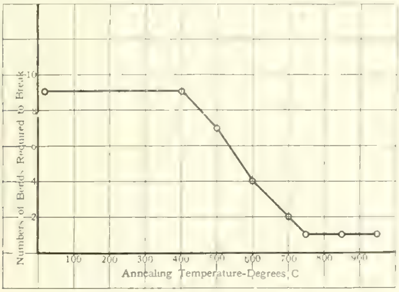

FIG. 6—EFFECT OF HYDROGEN ON BENDING RESISTANCE OF COPPER

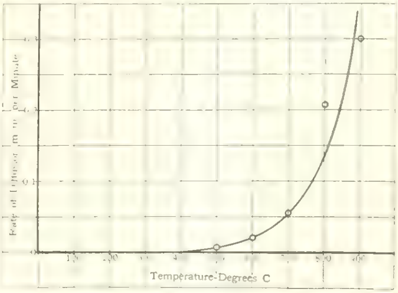

FIG. 7—RATE OF DIFFUSION OF HYDROGEN IN COPPER

The examples which have been given above are exaggerated cases of the fate that actually may overtake copper during its fabrication or during subsequent heating operations incidental to its use, providing the necessary combination of factors is present—that it is heated above 400° C in contact with reducing gases. A quarter inch rod was annealed in a large muffle furnace in which the products of combustion, containing a quantity of unburned gaseous material, were allowed to drift over it. When bent around a comparatively large radius, fracture occured in numerous places (Fig. 5) and close examination showed the existence of a friable outer shell about one sixteenth inch deep enclosing a tough unaffected core. Microscopic examination of an unbent section revealed the characteristic symptoms —a profusion of intercrystalline fractures and an absence of oxide granules (Fig. 8). The action, beginning as it does at the surface, and working inwards, may have a slight effect only when tensile stresses are involved, yet still be serious with bending stresses, the superficial fissures being strategically situated at the point where the fiber stresses are greatest. Once honeycombed with microscopic cracks the restoration of such copper to its normal condition is not feasible, as the internal surfaces become oxidized and non-weldable, and its usefulness is limited to the melting pot.

Another example is shown in Fig. 9, a micrograph taken from a copper frame which was brazed in a gas flame in such a way as to permit the flame to strike directly upon its surface. The affected layer was only 0.03 inch deep but was sufficient to cause the failure of a quarter inch square rod, and ultimately the whole structure, under long continued bending stresses.

A large coil of heavy section, insulated with impregnated organic materials, had the insulation burned off, an operation designed to bring about an evil combination of circumstances. The copper winding thus reclaimed was badly affected with hydrogenation (Fig. 10) and attempts to re-form it resulted in its failure.

In the examples just given the danger accompanying the practices illustrated is fairly obvious, knowing the obnoxious properties of reducing gases, but gases of this nature may be found in unlooked-for quarters, as for example the molten salt baths used in heat treating steel, which have lately been reported as containing sufficient dissolved hydrogen to render dangerous the immersion of copper articles in them.

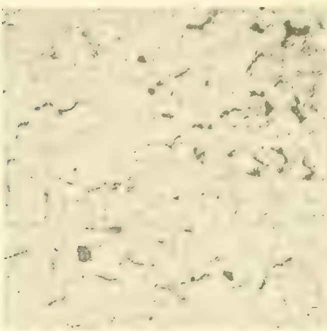

FIG. 8—ETCHED SHELL OF ROD SHOWN IN FIG. 5
Etched. × 100.

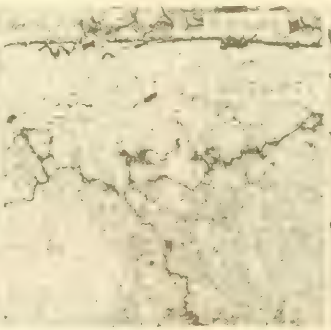

FIG. 9—INTERNAL FISSURES CAUSED BY REDUCING GASES DURING BRAZING
Etched. × 100.

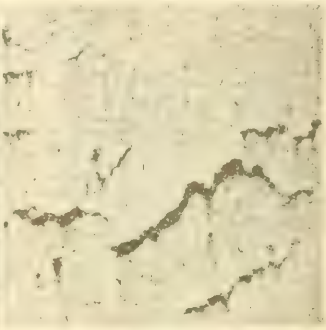

FIG. 10—SECTION THROUGH COPPER WIRE INJURED BY BURNING OFF INSULATION
Etched. × 100.

The statement of this problem has been its own solution. Prevention is the only cure. To avoid the difficulties detailed above there are three things which may be done:

a—Use oxygen-free copper.
b—Conduct thermal processes at temperatures at which copper is insensitive to reducing gases.
c—Exclude reducing gases from heating chambers.

Oxygen-free copper of high conductivity, suitable for electrical purposes, is not a commercial product. In the majority of the thermal operations to which we subject copper we do not have the liberty of action to limit the temperature, and our final recourse lies in the elimination of deleterious gases from the heating space, either by exclusion or by ensuring complete combustion. This is largely a matter of furnace design, in which the advantages of electric heating are obvious.

Mounting and Care of Small Ball Bearings

For Maximum Service

Geo. R. Bott
Engineering Manager,
The Norma Co. of America

THERE ARE MANY REASONS for the selection of ball bearings other than the one generally considered, viz., the reduction of frictional resistance to turning. Other features which the engineer who is responsible for the design of the apparatus should consider are:—

Maintenance of fixed centers in design.
Ease of securing true alignment.
Reduction of vibration to a minimum.
Accuracy and ease of turning.
Radial play of bearings in their mountings.
Endwise shift of shaft or axial play, as well as a fixed axial position of the shaft at one bearing position.
Fits in mounting bearings as recommended by the bearing manufacturer for the particular service or design.
High speed and low speed turning.
Eccentricity of bearings and shaft, and its effects.
Simplicity of mounting from an assembling and machining standpoint.
Ingenuity of mounting in providing for the least number of essential parts.
Facility of disassembling and inspection of bearings.
Provision in design for the protection of the bearings from foreign material such as dust, dirt, grit, moisture, vapors and against the loss of lubricant.
Saving in overall length by the adoption of ball bearings over sleeve or plain bearings.

After such points have been taken care of and properly designed bearings have been selected, it is obvious that accurate machining plays a prominent part in adding to the service that may be expected from the mounting and use of the bearings. With the ball bearing manufacturers specializing to deliver a uniform high grade and serviceable product in a condition well protected against the elements and against mis-handling, it becomes increasingly important for the user of bearings to give like consideration to the niceties of mounting, in order not to impair what has previously been accomplished with much effort and expense.

The actual mounting of bearings consists of more than providing a hole of indefinite character for the support of the outer ring of the bearing and a shaft of apparently round form to constitute the turning element. The bores for the bearings as well as for the shafts should be round or as near round as it is possible to make them by the methods of machining and finishing that are available today. There is an ideal for such work; and upon how closely the manufacturer or user is able to fabricate these parts, will depend on the amount of stress due to distortion and expansion that can be properly carried by the unit bearing. The better the fabrication the better the product. Nothing less than reaming (in quantity production) of the bores and grinding of the shaft for the mounting of the bearing rings is considered good practice for a uniform product.

With the bearings delivered in well protected packages and ready for use, it is well for the machine manufacturer to consider that his own interests are best served if such bearings are kept either in the original packages or under conditions which will provide a dry place for storage and protection from careless handling. It must be remembered that highly polished steel surfaces are affected by damp atmosphere, by perspiration and by dust, dirt or grit. The bearings should have individual and careful attention up to the point of mounting, and thereafter. Modern practice in production demands that bearings shall be systematically mounted with the least possible effect of the personal element that contributes to abuses. Where large production warrants, jigs and fixtures should be utilized for the easy manipulation of bearings in the process of mounting. Where a small number of bearings are used, this provision cannot be expected. Nevertheless, care should be exercised in the actual application of the bearings so as to provide against careless use of hammers, unsuitable tools, wrong assemblies, pinching, binding, scoring and other careless treatment which may tend to prevent the bearings from rendering satisfactory service.

For the proper assembly of units, it is quite essential to provide clean work benches and careful operators to insure the ultimate clean assembly of parts such as housings, plates, armatures, etc., and any further methods that will insure against possible contamination of the lubricant by materials such as chips, filings, dirt and grit. Carefulness in assembling prevents noisy operation of bearings and unsatisfactory wear and service. Too much importance cannot be placed upon this general rule of good practice, as will readily be appreciated by those who have had occasion to have apparatus disassembled, cleaned and reassembled at considerable loss of time and expense, all on account of thoughtless and careless habits of some assembling operator.

The question of lubrication for ball bearings, from the manufacturer's as well as from the user's standpoint, requires some special attention. The lubrication of the apparatus will depend somewhat upon the particular service which it is to give and somewhat upon the mounting that has been provided by the designer. To obtain maximum service, from ball bearings, it is necessary to provide a lubricant that will offer protection to the highly polished surfaces of the raceways and balls. This eliminates lubricants with free acid, alkali or moisture. Again, there should be sufficient lubricant to permit free, easy and continuous movement between the cages and balls. These requirements are a minimum. Any additional lubricant only operates as an insurance against future difficulties. It is here that the designer's work is most effective in the application of bearings, for he must give full consideration to such points as:—service to be performed, conditions of heating, the kind or quality of lubricant to be used and the possible attention that the bearing may be expected to receive in the way of lubrication. Both mineral grease and mineral oils are used for the different classes of service. Both will lubricate satisfactorily, if properly selected.

From the manufacturer's or first user's standpoint, it is evident that he must provide protection for the bearings to cover the period from the time of the assembly of the apparatus until it passes through the different stages of storage, shipment, handling and operation. The bearings must remain lubricated; and hence it is good practice to pack the bearings to about one-half of their volumetric mounting displacement with a good grade of petroleum grease. In small apparatus it is usual to provide means for the addition of mineral oil. In most cases this should be of medium consistency. With mountings so provided, it is well to assume that, when finally the apparatus is put into operation, the first real lubricating attention will be given by the ultimate purchaser or user. From then on, the manufacturer loses his control over the apparatus, other than to provide the usual guarantees against defective workmanship, and the apparatus must stand on its own merits as to operating efficiency.

Should the time come when the ball bearings need attention in the way of inspection, replacement, cleaning or other cause, it is only necessary to open the mountings, disassemble the parts and proceed with a thorough cleaning and inspection of both the housings and the bearings. Replacements, if necessary, may easily be made with new bearings procured from the bearing manufacturer or from the service stations established throughout the country. There is an element of time saving in this procedure for the reason that the standard bearings may be mounted without change in the original mountings without much effort or any loss of time. The reassembly of the unit brings the machine back to its original operating conditions with the same fixed centers, same conditions of rotation and the same original advantages that were built into the machine—a feature which has been much appreciated by those who are interested in the efficient, continuous performance of their product.

In remounting bearings, they should be partially packed with the proper grease, as previously described. Further, the subsequent addition of a medium grade of lubricating oil not only helps to keep up the consistency of the grease but aids by its fluidity in insuring a general distribution of the lubricating mixture.

As a general conclusion, it must be remembered that ball bearings are units in themselves, and that they will give long and lasting service if properly selected, properly mounted and occasionally given attention in the way of lubrication.

Heating Passenger Coaches

On the Chicago, Milwaukee & St. Paul Railroad

H. G. JUNGK
Railway Engineering Dept.,
Westinghouse Electric & Mfg. Company

HEATING PASSENGER COACHES drawn by electric locomotives brings up the problem of supplying heat to cars already equipped with radiators and piping for steam. This necessitates equipping an electric locomotive with a boiler and the necessary appurtenances. On the Chicago, Milwaukee & St. Paul Railroad in the Rocky Mountains, this problem is of considerable importance, because of the severe winters. To provide suitable facilities for generating a large amount of steam in a limited space, the locomotives are equipped with large boilers fired by crude oil.

In the middle of the cab a heating compartment is provided. This compartment contains the boiler, water tanks, oil tank, pumps, blower sets for forced draft and all the control valves. The apparatus is arranged to be operated from a platform in front of the boiler and all the valves, gages and auxiliary apparatus are arranged for convenient operation at that point. The two main channels of the cab support the boiler, tanks and floor. Overhead the cab roof is divided into three sections so that when removed all parts of the heating plant can be lifted out.

The boiler, 73 inches in diameter and 100 inches high, was designed by the Chicago, Milwaukee & St. Paul Railroad to generate 4000 pounds of steam per hour and to operate at 100 pounds pressure. In general, the boiler is of the vertical fire-tube type with a water leg extending up the entire height and with tubes inside running vertically from fire box to smoke chamber. It resembles the boiler of a steam locomotive set up on end and is built to take standard locomotive fittings. This simplifies maintenance as these fittings are carried in stock for the steam locomotives. To reduce heat loss radiation, the shell is covered with two inch lagging surrounded by a planished iron jacket.

The heat is produced by an oil burner mounted on the fire door frame. This burner, designed to burn crude oil, is started with an atomizing jet of compressed air and is operated with steam. The oil vapor is blown into a circular combustion chamber lined with fire brick. Forced draft is supplied through an air duct which enters the fire door frame below the burner.

The water supply is carried in two tanks. Tank *A* is behind the boiler and tank *C* in front. Their combined capacity is 3033 gallons. These tanks are mounted on the main channels and are removable. They are connected by two equalizing pipes, one of which is also used for draining, filling and suction for the feed water pump. The oil tank *B* is hung on the main channel below the boiler with a safe air space. This tank has a capacity of 750 gallons and can be filled from either side of the locomotive.

Water is pumped into the boiler by a single-cylinder feed water pump which operates either on steam or air. At a moderate speed, this pump is built to supply 150 boiler horse-power. At four gallons per hour per boiler horse-power, this would be 600 gallons. The pump is located on the floor in front of the boiler. Provisions were made to burn California crude oil. This oil is heavy, black and very sluggish, about the consistency of molasses. From data available such crude oil averages from 0.95 to 0.97 specific gravity or eight pounds to the gallon. The heat content is about 18 500 B.t.u. per pound with an average analysis of 86 percent carbon, 11.3 percent hydrogen, 0.7 percent nitrogen, 0.8 percent sulphur and the remainder of foreign matter. The flash point is between 150 and 200 degrees F. When cold, the oil is very sluggish and stringy. This necessitates preheating for use in cold weather. Oil for the burner is supplied by a small duplex oil pump mounted on the floor in front of the feed water pump. The oil pump is rated to deliver 780 gallons per hour at maximum speed. A large receiver drum is placed in the delivery line between the pump and burner to give an even flow of oil. Compressed air is used for starting and then steam is supplied for continuous operation.

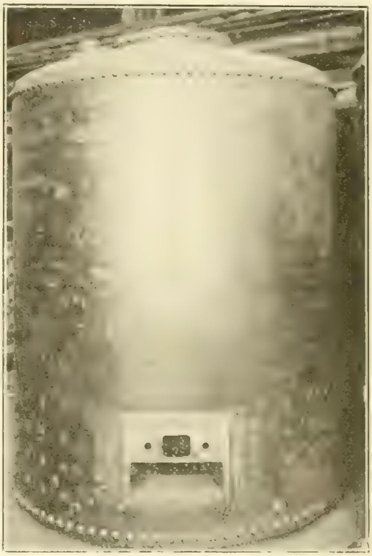

FIG. 1—[illegible]

The blower set for supplying the forced draft consists of a fan and motor mounted on a common bed plate with the fan housing in front of the fire door. A short air duct delivers the draft from fan to combustion chamber through the fire door frame. At 1800 r.p.m., the fan delivers 2650 cu. ft. with two inch pressure at the outlet, maximum capacity. For normal operation 1800 cu. ft. are required at one inch pressure. The motor is of the standard vehicle type totally enclosed and operating on the 85 volt auxiliary circuit. For controlling the speed of the set, an eight point controller is supplied. Both armature and field control are used. The controller handle, canopy switch, and fuses are mounted on the front of the panel with the resistance tubes hung on the back and the complete unit secured to the uprights at the side and in front of the boiler.

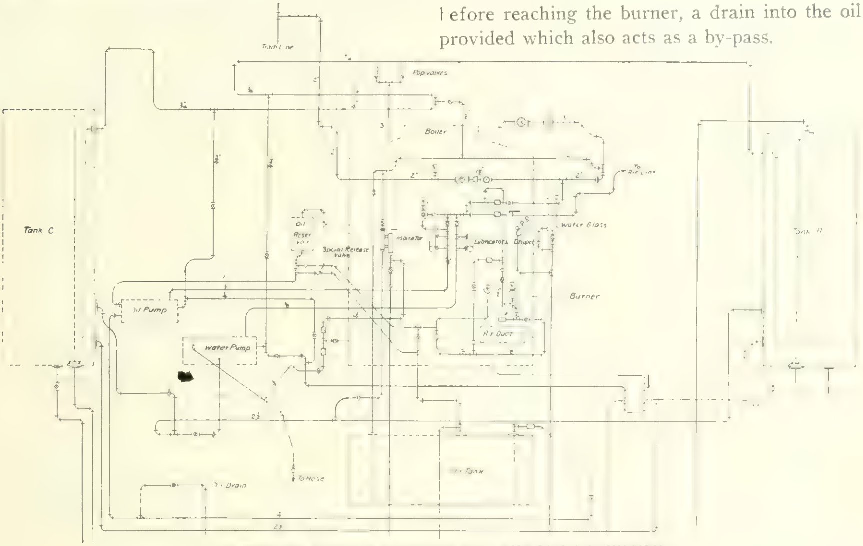

FIG. 2—PIPING DIAGRAM OF BOILER AND AUXILIARY EQUIPMENT

The main steam header takes steam from the dry pipe at the top and rear of the boiler, extends around to the front where the auxiliary steam header and the auxiliary steam-and-air headers are connected, and then crosses in front of the operating position through a special locomotive-type reducing valve and a globe valve to the train lines, which run along the roof of the cab over the aisle. The train lines run to both ends of the cab and down to flexible joints on the trucks to the steam hose and couplings. Cab radiators for the motormans compartments are tapped into the train lines at each end of the cab. The auxiliary steam header supplies the inspirator, used in case of feed water pump failure, and the live steam lines which warm the oil and water tanks. The auxiliary steam-and-air header takes steam through a globe valve and a check valve from the main header. Compressed air, from beyond the governor, is introduced into the header through an air cock and a check valve. This header supplies both pumps and the burner. In starting, air is used and for continuous service, steam is obtained from the boiler.

The oil line extends from the bottom of the oil tank up through a strainer tee to the pump. Then it runs to the receiver drum and on to the burner. Just before reaching the burner, a drain into the oil tank is provided which also acts as a by-pass.

The water line comes from one of the equalizing pipes between the tanks and extends to the inspirator and to the feed water pump, both of which deliver the water to the boiler through separate check valves. All steam, water, oil and air lines are provided with release valves and drains. The drains are particularly necessary in cold weather to prevent freezing. Live steam lines and exhaust lines from the pumps are connected to the oil and water tanks for preheating, although the pump lines are also arranged to exhaust into atmosphere if desired. All valves, gages and apparatus which must be manipulated during operation are located in front of the operator's position and, as a result, the entire plant is quite compact.

Regulation and Inductive Effects in Single-Phase Railway Circuits

A. W. Copley

IN LAYING OUT a distribution system for a single-phase railway, two of the main points to be considered are: 1—the regulation of the system, and 2—the inductive interference in neighboring telegraph and telephone lines. These two points are inter-related in that a change in the system which affects one will generally affect the other. A certain class of changes to better the regulation makes induction worse, and another class improves the conditions in the neighboring circuits.

IMPEDANCE OF THE TROLLEY—RAIL CIRCUIT

The first element to be considered in working out the regulation of the system is the impedance of the circuit composed of the trolley wire and return path. This impedance consists of the resistance of the trolley wires and the rails and the reactance due to the magnetic field between them. The resistance of the trolley wire is readily obtained as, for the railroad frequency of 25 cycles, it is practically the same as for direct-current. The rails, however, have higher resistance to alternating than to direct-current. The ratio between the 25 cycle alternating-current and the direct-current resistance has been experimentally determined as about 2.5 to 1. The reactance per mile due to the trolley wire is given by the formula,-

$$X = 0.110 \log_e \frac{d}{0.78r} \text{ for 25 cycles}$$

where d is the distance between the rails and the trolley and r the radius of the trolley. Likewise the reactance per mile due to the track is,—

$$X' = I' \, 0.110 \log_e \frac{d}{r'} \textit{ for 25 cycles.}$$

where I' is the proportion of trolley current which returns by rail, and r' is the effective radius of the two rails, or the geometric mean distance between the rails, which is equal to

$$\sqrt[4]{0.78 r_a d_{ab} \times 0.78 r_b d_{ab}}$$

where r_a and r_b are the equivalent radii of the two rails and d_{ab} the distance between them.

In the case of two wires being used as trolley conductors the same method applies for obtaining the proper value of *0.78r* for calculation of reactance. Likewise in the case of double or four track the geometric mean distance of the wires from themselves must be used in place of *0.78r* and the geometric mean distance of the wires from the track in place of *d*.

The radius for a single rail has been determined empirically so that the effect of the internal field in the steel may be neglected in calculations. For a 100 lb. rail, the value used is 0.35 in. Considerable variation of this value makes very little difference in the total reactance calculated and a high degree of accuracy for the effective radius of one rail is not necessary.

PROPORTION OF EARTH CURRENT

As mentioned above the proportion of current returning by rails must be known in order to have complete impedance data. This proportion has been determined by experiment in several cases and has also been calculated by approximate methods. The agreement between the results of tests and the calculations have been good. Local conditions affect the results to a certain extent but with the tracks well bonded and with ordinary leakage conditions, the values can be approximately stated and are as follows:—

Single track — rail current = 40 per cent of trolley current.

Double track — rail current = 60 per cent of trolley current.

Four track — rail current = 70 per cent of trolley current.

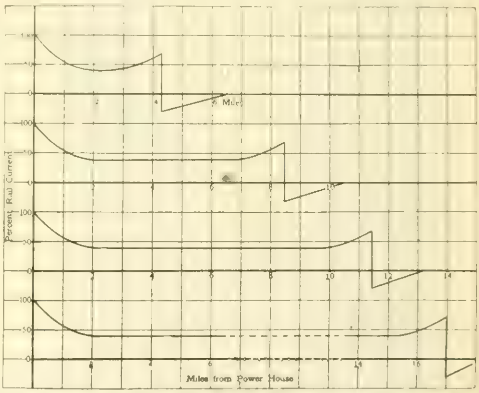

FIG. 1—EFFECT OF DISTANCE BETWEEN POWER-HOUSE AND LOAD, ON RAIL CURRENT OF SINGLE TRACK ROAD

The above values are such as would be measured in the middle of a section four or five miles long or more. For shorter sections, or for positions within two miles from the point of power supply, the values should be higher. The results of some of the first tests made on single-phase roads for the determination of earth and rail currents are shown in Fig. 1. The tests were made on the 25 cycle, single-phase line of the Indianapolis & Cincinnati, Traction Co. in 1906 which was then operating from Rushville Ind. to Indianapolis, a distance of 40 miles. For the tests, current was fed by trolley from the power house at Rushville to various points where the trolley was connected to the rails. The curves show how little effect the length of feed has on the division of the current between rails and earth. Further tests of a similar nature were made later on other roads, notably the N. Y. N. H. & H. R. R. which confirmed the results obtained at Rushville.

With the value of rail current determined, the impedance of the trolley-rail circuit may readily be calculated. A table of impedances for several sizes of trolley wire and different numbers of tracks is given in the appendix.

TOTAL IMPEDANCE FROM SUBSTATION TO LOAD

The vector difference of potential from a substation to a point fed by a single trolley from that substation is obtained by multiplying the impedance of the trolley-rail circuit by the current. If the point is fed from two substations between which two or more trolley wires run, the calculation can also be made quite simply. If the two stations are at the same potential the current to the load will divide between them in inverse ratio to the distance from them and the drop will be $m\ I_c\ Z_{bc} = (1 - m)\ \ I_c\ Z_{ac}$. If the two substations are at different potentials, the load current can still be considered as dividing inversely as the distance to the stations and, in addition, a drop will be added due to circulating current between the stations caused by their difference of potential. This drop is proportional to the distance from the substation. The potential drop from a to c, Fig. 2, due to the difference of potential between a and b is $m\ (E_a - E_b)$. The drop due to the load I_c at c is as above, the total being $m\ (E_a - E_b) + (1 - m)\ I_c\ Z_{ac}$. For a second load d in the same section distant m' from a and $1 - m'$ from b, the drop from a to c becomes $m\ (E_a - E_b) + [(1 - m)\ I_c + (1 - m')\ I_d]\ Z_{ac}$. This may be continued for any number of loads.

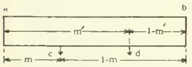

FIG. 2—TWO LOADS ON SAME SECTION BETWEEN TWO SUBSTATIONS

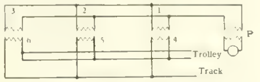

FIG. 3 GENERATING UNIT WITH STEP-UP TRANSFORMER AND TRANSMISSION LINE

With step-down transformers connected to trolley.

THE EQUIVALENT NETWORK FOR COMPLETE SYSTEM

The foregoing gives the electromotive force drops from substations to loads. The drop from the power house to the low-tension side of the substations can also be reduced to quite a simple calculation by considering the system, high-tension, low-tension and transformers, as a network. Fig. 3 shows such a simple system, comprising a generating unit P with a step-up transformer and transmission line and three step-down transformers stations which are connected to the trolley on the low tension side. The equivalent network is shown in Fig. 4. Z_0 = impedance of step-up transformer and high-tension line as far as 1, reduced to trolley potential, *i.e.*, the high tension impedance divided by the square of the step-down transformer ratios. Z_1, Z_2, and Z_3 = impedance of transformers *1*, *2* and *3* at trolley voltage. Z_a and Z_b = the impedance of transmission line from *1* to *2* and from *2* to *3* respectively, reduced to trolley potential. Z_c and Z_d = the impedance of trolley-rail circuit from *4* to *5* and from *5* to *6* respectively.

Distribution Currents—By the application of Kirchoff's laws, it is a very simple matter to find the currents which will flow in each transformer for load at any one on the low tension side. A chart can then be prepared as shown in Fig. 5, which shows the proportion of current supplied by each substation to a load at any point on the line. A load of one ampere at point X will be fed with 0.18 amperes from transformer station *1*, 0.34 amperes from transformer station *2*, and 0.48 amperes from transformer station *3*. A study of the chart shows that any load, such as that at X may be replaced by two loads at the adjacent substations inversely proportional in magnitude to the distance of the point of application of the load from them. The sum of the two equivalent loads must be equal to the original load. Such replacement or substitution may be made without affecting the transformer loads, and therefore, the e.m.f. drops to the low-tension side of the transformers are unchanged.

Self and Mutual Impedance—The values of self and mutual impedance which will determine the drops to the transformer stations can be calculated from the above data. For simplicity these impedances are designated as follows*:—

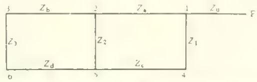

FIG. 4 EQUIVALENT NETWORK OF SYSTEM SHOWN IN FIG. 3

Z_{4-4} = self impedance to 4 or voltage drop from P to 4 for a load of 1 ampere at 4.
Z_{5-5}, Z_{6-6} = self impedance to 5 and 6 respectively.
Z_{4-5} = mutual impedance between 4 and 5 or the voltage drop from P to 5 for load of 1 ampere at 4.
Z_{5-4} = voltage drop from P to 4 for load of 1 ampere at $5 = Z_{4-5}$.
$Z_{4-6} = Z_{6-4}$ = mutual impedance between 4 and 6.
$Z_{5-6} = Z_{6-5}$ = mutual impedance between 5 and 6.

After the self and mutual impedances at transformer stations or other tie-in points have been obtained, the voltage drops to the low tension side of the transformers can be calculated for any fixed distribution of load. The equivalent loads at substations are first found for each individual load as explained above. These loads are then added and the system considered as one, with loads only at the transformer stations. To obtain the voltage drop to *4*, for example, the equivalent load at *4* is multiplied by Z_{44} the equivalent load at *5* by Z_{45}, the equivalent load at *6* by Z_{46}. The sum of the three results gives the value desired. The e.m.f. drop to any particular load may then be obtained by application of the formula given in an earlier paragraph on the trolley-rail impedance.

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*The simple and direct method by which these values may be obtained is illustrated in the appendix. The general features of the scheme have been described by R. D. Evans in the Electric Journal of Aug. 1919, and a mathematical proof of the reciprocal relation is given by C. L. Fortescue in the same issue.

System Fed from Two Sources of Power—A special case occurs when power is fed from two points. If the amount of current fed from the second point is known, it may be considered simply as a negative load and calculations are made in exactly the same way as for positive loads. If the amount of current fed from the second source is not known, it can be calculated by algebraic methods quite simply by considering it as an unknown negative load which maintains the voltage at its point of feeding, to the value for which the second source regulates.

Short-Circuit Currents—As the question of short-circuit currents will come up later when inductive interference is discussed, the methods for determining them will be briefly stated. The self impedance of the point on the system at which the short-circuit occurs determines the current, when the voltage and the impedance of the power plant are known. Any internal impedance in the power plant is added to the self impedance of the point of short-circuit and the generated voltage divided by this value gives the symmetrical r.m.s. value of the current.

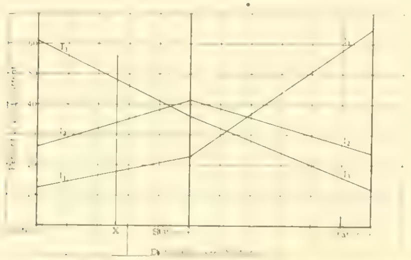

FIG. 5—PROPORTION OF CURRENTS SUPPLIED BY EACH SUBSTATION TO A LOAD AT ANY POINT ON THE LINE

In case there are two or more sources of feed, the calculations are a little more involved, but when the second source of power is considered as a negative load the calculation is somewhat simplified. Only the formulae will be given here and the mathematical proof and an example will be found in appendix A.

I_x = the current in the short circuit at X,

[illegible]

I_s = the current from secondary source of power,

[illegible]

Where E_o and E_s are the generated voltages at the main and second sources of power respectively, Z_s = the impedance of the second source of power, Z_{ss} = self-impedance to the point of application of second source of power, Z_{xx} = self-impedance to point of short circuit and Z_{sx} = mutual impedance between point of application of second source of power and point of short-circuit.

Formulae for obtaining the short-circuit current for any number of power stations can be worked out, although for more than two there is considerable complication. If, however, the generated voltages at the power stations are taken as equal to each other, which is generally an allowable assumption, the work is much simplified.

A special case of network is presented by the three wire distribution as applied to the N. Y. N. H. & H. R. R. electrification. This system utilizes the trolley line as one side and the feeder line as the other side of a 22 000 volt, single-phase transmission. Each line is 11 000 volts above the rail or ground potential and balancer or auto-transformers are connected at intervals between the trolley and feeder with the middle points connected to the rail, as shown in Fig. 6. The calculations for distribution of current, regulation, etc., are made in a manner similar to that for the plain two-wire system. In fact, an equivalent network exactly like that for the two-wire can be constructed and used for current distribution calculations. Impedance calculations to the low-tension sides of the transformers involve a little more work, as the mutual impedance between the trolley-track and the feeder-track circuits must be considered. Calculations of the voltage drop in the trolley-rail circuit of any single section is made in exactly the same manner as that for the two-wire system. In the appendix will be found a brief calculation showing the construction of the network.

INDUCTIVE INTERFERENCE

Two electric circuits paralleling each other have an effect one upon the other, due to the potential of and the current carried by the wires. A voltage on the wires of one circuit will induce a voltage on the wires of the other circuit. A change in the current flowing in one circuit will induce through the changing electro-magnetic field a voltage in the second circuit. The induced voltage from either cause is dependent upon the relative positions of the circuits. For a given position the electrostatically induced voltage is proportional to the potential of the inducing circuit and the electromagnetically induced voltage is proportional to the rate of change of current in the inducing circuit, or for alternating-current of a given frequency is proportional to the magnitude of the current.

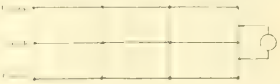

FIG. 6—AUTO-TRANSFORMERS CONNECTED AT INTERVALS BETWEEN TROLLEY AND FEEDER

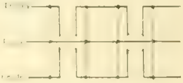

FIG. 7—EQUALIZER TRANSFORMERS CONNECTED BETWEEN TROLLEY AND FEEDER

Electrostatic Induction—A railway circuit consisting of a trolley wire and return in rails, earth or ground feeder and a parallel telegraph or telephone circuit consisting of a wire with earth or wire return present a case with possibility of induction from the causes mentioned. Considered in regard to the electric induction, a trolley wire is a conductor at a potential above ground with an electrostatic capacity to ground. The trolley wire also has a capacity to a paralleling telegraph or telephone wire which in turn has a capacity to ground. If the telephone wire were perfectly insulated from ground the potential would rise to a value determined by the relative capacity of the wire to the trolley wire and to earth. If the telephone wire is connected to ground either directly or through other apparatus, it will act as one plate of a condenser, the trolley wire being the other plate. Charging current will then flow from ground into the telephone wire, which will be proportional in magnitude to the capacities between it and the trolley wire. That interference from this cause is not probable is shown by experience on alternating-current railways which have been installed. Generally there is more than one wire on a telegraph or telephone pole line and the charging current is divided among these wires so that the amount in any one is insignificant. If one wire should be entirely insulated from the ground the others which are grounded cause its capacity to ground to be so much in excess of its capacity to the trolley wire that a high voltage is improbable.

Electromagnetic Induction—In working with the problem of electromagnetic induction, the trolley wire and its return may be considered as the primary winding of a large air-core transformer, the telegraph or telephone wire and its return being the secondary winding.* The induced electromotive force in a wire paralleling a circuit carrying current is proportional to the logarithm of the ratio of the distances between the wire and the two sides of the power circuit. If a telephone circuit is being considered, in which case there are two wires in which voltage is induced, the e.m.f. may be calculated for each, and the difference will be the voltage which will appear in the circuit. Such resultant induced voltage is caused by "transverse" induction or is due to the magnetic field between the two wires. The voltage calculated for a single wire is that which appears between the wire and the return at infinite distance, at which position the ground return can be assumed, and is caused by the magnetic flux linking with such a circuit, or the "longitudinal" induction. If the wire is grounded at one end, the calculated voltage will appear between the other end and ground. If it is not grounded at all and is uniformly insulated, the middle of the line will be at ground potential, and each end at one-half the calculated voltage from ground—one end being positive and the other negative. If the wire is grounded at both ends a current will flow through it proportional to the voltage and inversely proportional to the impedance of the circuit.

The transverse field can be made very small by so transposing the two wires of the telephone circuit as to cause them to have the same average position with respect to the inducing source. Perfect transposition, such as obtained by twisted pair or cable circuits, reduces the transverse induction to zero. The longitudinal induction, however, cannot be reduced by transposition of the telephone wires. This induction is the cause of voltages between the telephone line and ground and those appearing in grounded telegraph circuits. Longitudinal electromagnetic induction from transmission lines can be neutralized by transposition of the power wires. Transmission lines for railway circuits are no different in this respect from power lines used for general power transmission. Induction arising from the current flow in single phase trolley and rail circuits, however, presents a different situation on account of the impossibility of transposition of the two sides of the power circuit. The magnitude of the electromagnetically induced voltage can assume rather large proportions with such a circuit, as compared with even an untransposed power circuit of ordinary dimensions, because of the distance between the two conductors, the trolley wire on one side and the return circuit made up of rails and earth on the other side.

Position of Earth Current—If all current returns by rail the induced voltage at 25 cycles per mile per ampere is $0.116 \log \frac{D}{D'}$, where D and D' are the distances of the trolley and rail respectively from the telegraph wire. It is easily seen that at a distance of a few hundred feet D and D' would become practically equal and the value of the voltage, therefore, would be zero. If part of the return current flows in the earth the induced voltage becomes $0.116\, I_t \log \frac{D}{D'} + 0.116\, I_e \log \frac{D''}{D}$ where I_t and I_e are the track and earth currents and D'' the distance between the telegraph wire and the path of the earth current. This latter is an unknown quantity and can only be estimated. Tests made in various places have given quite different results. The determination of the effective position of the current for any given case is quite easily made, providing measurements have been obtained of the values of I_t, I_e, D and D'. On the single track line of the Indianapolis & Cincinnati Traction Company, tests and calculations showed the effective position of the earth current to be about 400 feet below the surface. On the N. Y. N. H. & H. R. R. and on the Pennsylvania Railroad, which are four-track roads, the effective position of the current as calculated from the inductive effects is 5000 feet below the surface. Tests on the N. & W. R. R., a two-track road, agreed more nearly with I. & C. Traction Co. results, but these tests were not as extensively carried out as at the other places.

There is another method of obtaining the effective position of the earth current which does not involve telegraph line voltage measurements. This uses the distribution of current between the earth and track in connection with the known characteristics of the track circuit. Assuming that the earth current is distributed uniformly in a cylindrical conductor tangent to the surface at the tracks and having zero resistance, the reactance may be calculated, and from the reactance the diameter of the conductor may be deducted. Calculations of this kind have shown the effective center of the earth current to be from 200 to 600 feet below the surface.

While many of the calculations seem to favor a position of earth current about 500 ft. below the sur-

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*Griswold & Mastick, *A. I. E. E. Proceedings*, Sept. 1916, p. 1339.

face, it is not considered that this value is a safe one to use in calculating the induced voltages in communication circuits when laying out a system. It is probable that the earth current is not uniformly distributed and possibly it does not penetrate into the earth to any great distance, but is spread out in a layer a few feet or a few hundreds of feet thick and a mile or so wide. Up to the present no single method for calculating the position of the current has proven itself correct for even the few cases for which tests have been made. It is recommended therefore that on new projects where it is impossible to obtain actual measurement of induced voltage per ampere, the value of 5000 feet be used, as it will probably give results within a reasonable degree of accuracy and at least will err on the safe side. For calculating induction in conductors placed within 50 ft. of the trolley it is safe to use a lower value, say 1000 ft. for the depth of the current.

Total Value of Induced Voltage—When the induced voltage per ampere is known for each section of the line it is an easy matter to calculate the total voltage for any given load conditions, by calculating the voltage for each part of the line in which the current is uniform and adding or subtracting the voltages of these sections according to the flow of current. It will be noticed at once that in a layout such as shown in Fig. 2, there will be a neutralizing action for any load between transformer stations, as current will flow in opposite directions on either side of the load. A stub end feed in which all the current comes from one direction is much more severe for induction. If a load is at one end of the network, however, there is the condition of feed in one direction from all substations except the one at which the load is applied. It is necessary to keep such through feed currents to a minimum in order to restrict induced voltages to a low value.

The limiting condition for induction is generally not the normal load condition, which can usually be kept so distributed in a system fed by several transformer stations, as to cause a good deal of neutralizing action. Short circuit conditions, however, always have the effect of concentrated loads, and if the short-circuit occurs at the end of a system the through feed is most harmful.

EFFECTS OF INDUCTION IN TELEGRAPH AND TELEPHONE LINES

Telegraph Lines—The effects of the induction can be stated quite simply for telegraph lines. If the induced voltage rises above certain rather definite values, the telegraph instruments chatter and cannot be used. It has been found experimentally that ordinary simple Morse circuits can stand a voltage of about 40 percent of the amount of direct-current battery used. Duplex circuits can stand about 80 percent, while quadruplex is more sensitive and can stand only 15 or 20 percent of the direct-current battery potential under fair operating conditions. Short-circuits are generally not as serious as continued loads, as the disturbance passes quickly and repetition of a word or two of the message is usually the only inconvenience caused. There is a possibility of cases, however, where such a disturbance would simply distort the signals so as to allow a wrong interpretation of the message. So far as is known there have never been any cases of the kind detected.

Telephone Lines—The effects in telephone lines on the other hand are most seriously felt during short-circuit conditions. Metallic telephone circuits are protected at the ends by carbon block protector gaps between each wire and ground, these gaps being designed for a breakdown of 400 volts or thereabouts, but maintained in certain instances to stand a 200 volt direct-current test. Unless these break down or other grounds occur on the lines, telephones are seldom disturbed by induction from single-phase railway currents as they are two-wire circuits and usually transposed and balanced sufficiently to keep noise from the operation of trains to a permissible value. Cable lines are particularly good in this respect, whereas open wire lines are more susceptible to trouble. If the two wires of the telephone circuit are not so transposed as to give equal induced voltages in them, noise will result, also even if the wires are well transposed there is liability of noise due to unbalance in capacity or leakage resistance to earth. The noise is not caused directly by 25 cycle current but by ripples on the main frequency wave which are present in the trolley current. Most of the telephone troubles have been found to result from a breakdown of the protector gaps. Such breakdown is dependent upon the magnitude of the induced potential under the short-circuit conditions, which depends upon the absolute rate of change of railway current flow.

Among the troubles caused by gap breakdown, the principal ones are bell-ringing, loading coil trouble, and acoustic shock. If the gap fails there is the danger of cable or exchange wiring insulation breakdown and of electrical shock, although there are no instances of this on record for lines subject to railway induction. If the insulation on the board breaks down there is added a fire hazard. There is also a fire hazard due to voltage which does not approach the breakdown value of the protector gap providing such voltages are sustained for several seconds or minutes. Sustained voltages will be found during train operation, but generally speaking, if the voltages occurring during short-circuit are not high enough to cause hazard from the causes mentioned above, the normal sustained operating voltage will not be high enough to cause fire hazard. The various troubles should probably be explained more fully.

Bell Ringing—This is simply a ringing of the subscribers' bell or the operating of the drop at the central office which, while not of a very serious nature, is an annoyance which should be reduced to a minimum.

Loading Coil Trouble—This will occur in loaded trunk lines. The two wires of the telephone line pass through the loading coil windings and if the protector gap on one line breaks down, more current will flow through one winding than through the other, sometimes permanently changing the permeability of the iron and rendering the coil inefficient. This effect is produced by the magnitude of the current, independent of its frequency.

Acoustic Shock—This is caused by loud noise in the receiver in case a gap breaks down with any heavy discharge following. It is experienced chiefly by operators and is considered a serious condition.

Electrical Shock—Operators and switchboard or line repairmen will be subject to this hazard.

Fire Hazard—Any breakdown of insulation on the board or in the exchange wiring is liable to cause fire, provided enough current flows. Telephone engineers have stated that a breakdown of insulation at 200 volts with one-half ampere flowing for two seconds is considered as a possible cause of fire.

With the above points in view it can be said that if the maximum induced voltage for a period of two seconds is not over 200 volts the chances for trouble in the telephone circuits would be very small. For a longer time, covering several minutes, an induced voltage in the neighborhood of 100 volts or less is probably safe and for a shorter time than two seconds it would appear that higher voltages than 200 can be tolerated. In many cases voltages of several times 200 volts have been induced with no bad results aside from bell-ringing even when continued for one or two seconds. Just where the safe limit of voltage is for a duration of time represented by a short circuit (less than one-half second) cannot be stated. For equal fire hazard the allowable voltage should increase inversely as the square root of the time. None of the above limits can be considered as hard and fast, but represent opinions gained after a study of the records of telephone disturbances and general conditions obtaining in the communication circuits.

SYSTEMS OF FEED WHICH TEND TO REDUCE DISTURBANCE

In laying out the transmission line and transformer stations very much can be done which will tend to make the system harmless as far as telephone induction is concerned. Some of the points which can well be considered have already been suggested.

Location of Transformer Stations—Probably the most harmful railway system from the viewpoint of the telephone or telegraph engineer is one in which the trolley is fed for several miles from one end only. If any telegraph or telephone lines parallel such a system, they are pretty certain to be disturbed. Feeding by a transformer station at the end opposite from the first feed-in point will reduce induced voltages to about 30 percent and sometimes to considerably less than this. A liberal use of transformer stations is one of the best cures for the induction evil. The characteristics of transformer stations, the impedance of the trolley-rail circuit, the transmission line impedance, all can be adjusted so as to reduce the through feed factor, and the impedance of step-up transformers can also be varied to advantage. Each particular case must be treated individually and no set rule can be given to eliminate inductive troubles. In general through feed is reduced by increasing the trolley-rail impedance and decreasing the impedance of step-down transformers and transmission lines. The trolley-rail impedance is determined by the size of the trolley wire, which in turn should be determined by the carrying capacity of the wire. This will give the highest impedance permissible for the trolley-rail circuit. Step-down transformers should then be made of as low reactance as is compatible with cost and the transmission line impedance kept low in comparison with that of the trolley-rail. With these factors determined and the regulation desired fixed, whatever reactance is still allowable should be put in the step-up transformers and generators so that short circuit currents will be as small as possible.

Sectionalized System—In cases where telephone wire exposure is very severe and through feed conditions must be reduced beyond the amount given by the above methods, good results can be obtained by sectionalizing the transformer stations, *i.e.* using two transformers at each station with the high-tension sides paralleled, but with the low-tension sides separate, one transformer feeding each direction. This impairs the regulation of the system somewhat, unless the load is well distributed.

If these points are carefully considered in laying out the system, it will be found that the addition of any special devices, such as will be spoken of later, may be in a large measure, if not altogether, obviated.

Three-Wire System—The three-wire scheme as applied on the N. Y. N. H. & H. R. R. is a special form of multiple transformer station system. This system has all the advantages of the plain two-wire system which has been mentioned above, with the added advantage of using autotransformers which,for equal capacity, are smaller than two coil transformers, and of using the copper trolley as part of the transmission circuit. Transformer stations can, therefore, be placed a little closer together for the same cost, and induction will be reduced if this is done. The transmission voltage is limited, however, to a value of double the trolley voltage. The calculation of the induction in telephone and telegraph lines is made in exactly the same way as described for the simple two-wire system.

Sectionalized Three-Wire System—Several schemes for the sectionalizing of a three-wire system at the transformer stations have been worked out. Some of them have been tried in the laboratory with very good results, but none have been applied in practice. The simplest of these schemes is shown in Fig. 7. Equalizer transformers with one to one ratio are connected between trolley and feeder lines at the transformer stations so that the current in the trolley and feeder windings must be equal. The equalizer must have a current capacity equal to the total line current at the point at which it is installed and a voltage rating equal to the e.m.f. drop in the autotransformers at the station where it is installed. If short-circuits are to be cared for without any through feed this means an equalizer transformer rating of full trolley voltage (11 000 volts) but if a small amount of through feed is permissible under severest short-circuit conditions, a lower rating can be used.

SPECIAL DEVICES FOR INTRODUCTION INTO RAILWAY CIRCUITS TO REDUCE INDUCTION

What has been said covers generally the whole system of distribution on the railroad. There are, however, certain minor changes which can be made which have the effect of reducing induction. The object of such devices is to reduce the earth current.

Ground Feeders—Overhead return feeders will allow a portion of the return current to flow in them and so reduce the rail and earth currents. Calculations have been made which indicate that the induction may be reduced in the neighborhood of 30 to 50 percent by using a 4/0 wire as return feeder, paralleling each pair of rails, if the feeder is placed within a few feet of the trolley wire.

If a return feeder is placed close to the disturbed telegraph or telephone line, the reduction in induced voltage for that particular line is greater. The current carried by such a feeder will depend upon the voltage impressed upon it and its impedance. If the feeder circuit impedance were entirely reactance, the current flow would be of the correct phase and approximate amount to neutralize the voltage appearing in the telephone line, with the feeder wire simply connected to earth. But even if the wires were large, the resistance of ground connections would be so high, ordinarily, that the current would be too small for anything like complete neutralization. Connection to the rails gives a circuit of lower impedance. In order to get a current in the feeder of the desired amplitude and phase, however, it is necessary to use some such device as a booster transformer between it and the trolley wire. With such an arrangement, distribution of the transformers and conditions which might cause saturation must be carefully considered, as brought out in the following paragraphs on track and feeder boosters. This scheme has never been applied on account of the many practical difficulties against it.

Booster Transformers—The device which has been used more than any other for accomplishing the reduction of induced voltage is the booster transformer for track or for a feeder close to the trolley wire. This is a transformer whose primary winding is connected in series with the trolley circuit and whose secondary is connected in series either with the track or a return feeder, the primary and secondary ratio being approximately one to one. The use of a return feeder overhead in connection with booster transformers is objectionable first from the standpoint of cost. The feeders are used instead of the track for the return path for the current, and in order to keep the regulation of the line within reasonable limits they must be of large section. Two 100 lb. rails have a resistance to 25 cycles of approximately 0.08 ohms per mile, which is equivalent to about three 4/0 copper wires. Smaller feeders, of course, may be used at the expense of regulation and an increased size of the booster transformers. The voltage rating of the transformer must be the voltage drop in the section of feeder to which it is connected. The advantage of the use of the return feeder rather than the track, lies in the greater reduction of induced voltage in telegraph and telephone lines running very close to the railroad. The use of booster transformers connected to the track utilizes the low impedance return circuit which the rails provide and saves the cost of the copper feeders. The impedance of the trolley-rail circuit is increased a little over the value when no boosters are used, on account of the current being forced to return entirely by rail, and on account of the impedances of transformer windings. The increase is shown in the tables given in the appendix.

Booster transformers, when of sufficient size and used in sufficient numbers, give very good results in actual service. There are practical limitations, however, both as to size and number. The limitation as to size appears in the voltage across the secondary. This is limited, especially in the case of the track booster, as it is not advisable to introduce high voltage between two adjacent sections of track either under normal operating conditions or during periods of short-circuit. The maximum voltage allowable under short-circuit conditions can probably be taken as the limiting value. Once this is set the number of transformers necessary is easily determined by spacing them at such intervals that the maximum voltage drop in the sections of track will be less than the limiting value of the voltage. It will be found on the larger electrifications that quite a close spacing will generally be necessary, *i.e.*, one, two or even more per mile being required. The objection to close spacing lies in the number of insulating joints or section breaks in the trolley or track to be installed and maintained. With a return feeder, spacing closer than a mile apart may not be necessary but the voltage of the individual transformer must be correspondingly raised.

When transformers are not installed in sufficient numbers complications result, especially under short-circuit conditions. When the short-circuit occurs the transformer iron becomes saturated and the voltages across them take on a decidedly peaked wave shape which is hard on insulating joints and on short telephone lines with a terminal close to a booster transformer. Moreover, the induced voltages in all telegraph and telephone lines is peaked and in some cases will rise to values considerably in excess of the values which it would attain were the boosters not in the circuit. The latter phenomenon is due to the fact that with boosters there is always a residual current in the earth, this current being the magnetizing current of the transformer. Under saturated conditions the magnetizing current is not only large but is of distorted wave shape. As far as short-circuit conditions are concerned it is better not to have any transformers in service than to have so few that saturation will occur. Track boosters are here at somewhat of a disadvantage as against feeder boosters, as the former are apt to be short-circuited by trains on the tracks at insulating joints and so possibly many of them would be out of commission at the time they are most needed.

CONDITIONS OF RAILWAY OPERATION

It is possible so to operate a well laid out road, as far as induction is concerned, as to cause severe inductive effects in telephone and telegraph lines as well as to give poor regulation. A few simple precautions, however, if observed, will generally prevent trouble from these causes.

One way feed to a load gives best opportunity for inductive troubles to appear. Therefore the circuit breakers should be closed on both ends of a section of trolley on which there is any considerable load. On a multiple transformer station system, precautions should be taken against operation with an end station out of commission and with considerable load in the end section. This condition gives a stub end feed on all tracks from the next transformer station. Provision should be made in the end station to minimize the possibility of such operation becoming necessary. If circuit breakers are to be cut out for inspection or repair, such work should be done when the section is not loaded, or spare apparatus should be available so that the feed from the end station will not be interrupted.

On a sectionalized system, it is necessary to see that train loads do not get spaced so that they are one substation apart. It is conceivable that such a condition might be obtained, although it is unlikely. If all the trains were leaving or all approaching substations, in relatively the same positions, under such a condition, the current feed in the trolley would in effect be entirely in one direction and therefore inductive interference might become severe.

Under short-circuit conditions, the circuit breakers should operate quickly as well as selectively. A short-circuit is a heavy concentrated load. If it be in the middle of a section the current feeds in the two directions and will tend to neutralize their individual effects but if the short-circuit is at the end of a section—especially in the case of an end section—the inductive effect can become very high. It is therefore desirable that circuit breakers be set to operate so quickly that the induced voltage will not last long enough to cause trouble. High speed under such conditions is not incompatible with selective action, as the high speed is necessary only when the current is so high that there is no doubt that the circuit breaker is feeding directly into the short-circuited section, and the trip can be set to operate under this condition irrespective of the time relay which controls it under lower values of overload. Thus selectivity is obtained on heavy short-circuits on account of the fact that only circuit breakers feeding directly to the short-circuit can have enough current to operate the trip directly, and on high resistance short-circuits because of the time limit relays.

SPECIAL DEVICES FOR INTRODUCTION INTO TELEPHONE AND TELEGRAPH LINES

Certain schemes which have been used involve the introduction of apparatus directly into telephone or telegraph lines in order to neutralize the induced voltage or to keep it from causing disturbance. Much progress has been made along this line and several schemes have been proposed, many of which have been tried out experimentally, and found satisfactory up to certain limits, and there are others which have actually been put into regular service.

The Neutralizing Transformer—First among these is the neutralizing transformer. It was proposed for use on the New York, New Haven & Hartford Railroad before the electrical operation of the road was begun and one pole line in the worst exposure was equipped in time to take care of the heavy induction which ensued when trains began to operate. Under normal operating conditions the induced voltage on the telegraph line paralleling the road frequently rose as high as one thousand volts, yet the wires were worked as usual without serious interruption. Other lines were later equipped with the device.

The neutralizing transformer is simply a multiple secondary, one to one ratio (approximately) transformer, whose primary is connected into circuit with a wire running among the wires to be protected and grounded at the ends of the electrification, and between the transformers if more than one is used. Each telegraph wire is connected to a separate secondary winding so that the voltage of the windings opposes the induced voltages in the wire. The residual voltage in the telegraph or telephone lines is limited by the resistance of the neutralizing or pilot wire and the magnetizing current in the transformer and under normal conditions is equal to the product of these two. The objection to its use is mainly in the transmission loss added to the telegraph or telephone line. While loss in transmission efficiency is not great, it is considered objectionable when it is considered what extreme measures are taken by telephone companies to improve the transmission of their lines. It is not economical when used on long lines when the induction is only moderate in amount. On the N. Y., N. H. & H. R. R. the amount of neutralization obtained on the main telegraph pole line was approximately 95 percent, the residual voltage being five percent of the total induced voltage.

Increase of Resistance of Telegraph Wires— For induced voltages of moderate value it is sometimes possible to insert resistance in a telegraph circuit and raise the direct-current working voltage accordingly, so that the ratio of induced voltage to direct-current potential does not exceed the allowable amount. Impedance added also tends to reduce the disturbance although it slows up slightly the working of the telegraph circuit.

Resonant Shunts have been tried and are now being used in several telegraph lines. One type of shunt consists of a parallel resonant circuit for 25 cycles, and so is in effect a very high resistance to this frequency. For direct current, however, it introduces very little resistance. When it is connected in series with the telegraph instrument, the telegraph current, which has a relatively steep wave front, passes through the condenser at the beginning of the signal, and the sustaining or the following current flows through the inductive reactance with a small voltage drop due solely to the resistance of the coil. This kind of a shunt may be used directly in a Morse circuit or in the relay circuits of a duplex or composite outfit.

A circuit in series resonance for 25 cycles can be placed in parallel with the telegraph relay and such an arrangement will cause the alternating current to flow through the resonant circuit rather than through the relay. The device has been successfully applied and has worked well with an induced potential ten times the maximum allowable without protection.

Variations of these two devices constitute most of the other schemes proposed with the same end in view. Some of these schemes have been experimented with in Europe and several apparently have considerable merit. Those which have been tested in telegraph lines along the Pennsylvania Railroad Philadelphia-Paoli electrification are shown in appendix B.

Telephone Circuits—There is some objection to the interposition of corrective devices in telephone lines on account of the high transmission efficiency which must be maintained and the more delicate nature of telephone instruments when compared with telegraph instruments. The neutralizing transformer has been used for telephone circuits, but it must be wound with each secondary composed of two wires wound side by side so as to prevent the introduction of impedance directly into the talking circuit. While they are more expensive than the transformers made for telegraph circuits, still the principal objection to their use is the loss in transmission efficiency.

Telephone trunk lines have been operated in the neighborhood of railway circuits which induce potentials in them, with reactance coils bridged across the telephone line with the middle points grounded. With a device of this kind at each end of the trunk circuit no 25 cycle voltage can appear on the switchboard, but the transmission loss again appears as an objection.

The main safeguard against telephone trouble seems to be in the maintenance of the line in good condition and depending upon the protector gaps to remove hazardous potentials.

Lead Covered Cables—The use of lead covered cables for either telephone or telegraph lines has an advantage besides the easier maintenance, in that the lead sheath acts as a return feeder close to the telephone wires. There are objections to connecting the lead sheath to the rails and so the full value of the return is not felt, but experience indicates that the lead sheath on a large cable reduces the induction by about 10 to 30 percent.

Insulating Transformers—Telephone instruments may be connected to the telephone line through repeating transformers and thus prevent any induced voltage on the line from being transmitted to the instrument. This scheme is particularly applicable to private telephone lines, such as those from substations to powerhouse, etc. It is often used for lines running on the same poles as high-tension transmission wires. Transverse induction is not protected against by the transformer, and therefore there is no reduction in noise resulting from imperfect transposition or protector breakdowns. Transmission loss is involved in the transformer, but this is generally not serious on a private line, providing not too many transformers are bridged across one pair of wires.

INDUCTIVE INTERFERENCE FROM EXISTING SINGLE-PHASE RAILWAYS

The first roads to adopt the single-phase, alternating-current system were interurban trolley lines. The traffic was light compared with later installations, but the voltage was lower and therefore the current was high enough to give as much electromagnetic induction as a higher voltage, high powered line. The first study of inductive interference was made on the Derry and Latrobe line, a short line in Pennsylvania run at a trolley voltage of 1000 volts. The tests made there gave enough information to enable a more comprehensive set of tests to be made on the 3300 volt Indianapolis & Cincinnati Traction Company line running from Indianapolis to Rushville, Ind. a distance of 40 miles. It was during these tests, in 1906, that an idea of the division of return current in rail and earth was first obtained with any degree of definiteness. The neutralizing transformer for use in telephone and telegraph lines was also first tried out during these tests, with the result that it was considered advisable to depend upon this scheme for taking care of the inductive interference problems of the New Haven electrification.

The Indianapolis and Cincinnati electric line did not cause serious interference in neighboring circuits, principally because it was broken into sections of about ten miles in length, each section being fed from a separate transformer station. The line has since been extended, using the same feeding system, and inductive interference trouble has not occurred.

The New Haven electrification was first laid out with only one point of feed, at Cos Cob, near one end of the line. Induced voltages in the railroad telegraph line running on the right of way were calculated from the data obtained on the I. & C. line and the values indicated were checked later by test and found to be substantially correct. The neutralizing transformer scheme was adopted and the transformers were put in position and connected before operation began. The result was that the railroad telegraph lines gave successful service and were operative even when the induced voltage was as high as 1000 volts. The transformers neutralized this enough to keep the residual below 50 volts. When short-circuits occurred on the line, the transformers probably were saturated and the residual must have been in the neighborhood of 1000 volts and possibly more, but no damage was caused. The relays would rattle for a second, or until the short-circuit was cleared, and this was the only result.

The American Telegraph & Telephone Company had lines paralleling the New Haven at a distance of a few hundred feet. These lines were worked as telephone lines during the first months of the electrification with no inconvenience, other than some noise in the open wire circuits. The voltage under normal operation reached values of about 200 volts, and under short-circuit conditions it must have reached several times this amount, although no measurements to determine the maximum values were made. The lines could not be used for composite telephone and telegraph service, however, and for this reason neutralizing transformers, especially built so as to be suitable for composite circuits were installed.

The increase and extension of the New Haven electric service necessitated a better system of feed, on account of voltage regulation and also because of the increased induced voltages. The three-wire system was adopted and the entire line was changed to this scheme. The result was very beneficial to telegraph operation and it has been found possible to operate the railroad telegraph circuits with the neutralizing transformers cut out of service with very little disturbance, although the length of the electrification, and therefore the exposure of the lines, is three times as great as when the road began operation under the old system of feed.

The scheme of using track booster transformers was given a test in the spring of 1914 on the New Canaan branch of the New Haven Railroad, which is a seven mile stub end road branching from the main line at Stamford, Conn. The tests showed that this scheme was workable and it was installed on the branch, clearing up the inductive interference there.

The same scheme was applied on the Norfolk & Western Railroad and has given successful results. It was brought out in tests at this place that the transformer scheme was not giving as low an induced voltage as indicated by the New Canaan experiments. This was found to be due to abnormal leakage around insulating joints, on account of the kind of ballast and a water piping system close to the rails. However, the induction is not such as to cause interference at present. The distribution system is on the multiple substation plan.

The Philadelphia-Paoli electrification employed booster transformers at the start, on account of the railroad telegraph circuits which, without boosters, would have between one and two hundred volts induced during normal operation. Telegraph operation was perfect, but considerable bell ringing trouble at times of short-circuits was caused in the Telephone Company lines and investigation traced the cause to the saturation of the boosters. The resonant shunt for telegraph lines was developed and connected into the telegraph circuits in order to allow the removal of the boosters, with the object of getting rid of bell ringing. Boosters on one half the line have been removed and resonant shunts installed in the telegraph lines with very favorable results. The telegraph business of the railroad is carried on as duplex composite, four wires making up a set of four duplex telegraph circuits, two direct telephone circuits and one phantom telephone circuit. Bell ringing in telephone lines has been practically eliminated.

On the latest single-phase electrification in the United States, which is that of the Chestnut Hill branch of the Pennsylvania Railroad at Philadelphia, a careful study of the substation layout was made prior to the installation, with the idea of keeping inductive interference to a minimum. The transformer stations were located with this in view, and the result has been that it has been unnecessary to install any corrective devices, either in the railway circuits or the communication lines. This line went into service two years ago and no case of bell ringing or other disturbance has been reported.

Other single-phase electrifications have been installed with multiple substation systems, and the inductive interference has been practically negligible. The special cases mentioned above are those in which special investigations and tests seemed desirable, and are therefore those on which the most data is available.

CONCLUSION

In planning for an electrification which is paralleled by telephone and telegraph circuits, it is essential that induction be taken into account from the start. The introduction of special devices into either the telegraph or the railway circuits is annoying and sometimes quite expensive. By carefully laying out the transformer stations and determining the probable induced voltages beforehand, very little extra expense should be involved and a system can be obtained which is free from most, if not all, of the extra devices. If the stations are so laid out that the short-circuit conditions on the railroad do not cause dangerous voltages in the telephone lines, normal operating conditions will, as a general rule, take care of themselves. If, after all reasonable steps have been taken in the railroad circuit, the induced voltage is still above the working limits and yet does not cause a physical hazard, the use of some such device as the resonant shunt in the telegraph lines will probably take care of whatever voltage remains. If there is a short distance where the exposure is very severe, and the spacing of transformer stations to take care of this condition would be so close as to cause considerable expense, such a short stretch could be protected by some of the special devices considered above, without affecting the rest of the system.

APPENDIX A

TWO-WIRE NETWORK

To construct the equivalent network, reduce all impedances to a base voltage (trolley voltage is preferable as base). For example, in Fig. 8,

Z_a, Z_b = impedance of feeders.
Z_c, Z_d = impedance of trolley-track.
Z_1, Z_2, Z_3 = impedance of step down transformers.
Z_0 = impedance of step up transformers and feeder to *1*.

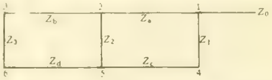


FIG. 8—EQUIVALENT TWO-WIRE NETWORK

First consider mesh *2-3* separately and as fed from *2* with one ampere load at *5*, Fig. 8.

$$I_3 = \frac{Z_2}{Z_b + Z_3 + Z_d + Z_2} = m$$

$$I_2 = \frac{Z_b + Z_3 + Z_d}{Z_b + Z_3 + Z_d + Z_2} = n$$

$I_2 Z_2 = Z_{235}$ = impedance of network 2-3 from 2 to 5.

Consider mesh *1-2* with side *2-5* made up of mesh *2-3*. For a load at *4*,

$$I_1 = \frac{Z_a + Z_c + Z_{235}}{Z_a + Z_c + Z_1 + Z_{235}} = K$$

$$I_{235} = \frac{Z_1}{Z_a + Z_c + Z_1 + Z_{235}} = L$$

$I_1 Z_1 = Z_{44}$ = self impedance to *4*.
$I_2 = nL \qquad I_3 = mL$
Z_{54} = [illegible]
Z_{64} = [illegible]

For load at *5*,

$$I_1 = \frac{Z_a + Z_{235}}{Z_a + Z_c + Z_1 + Z_{235}} = K'$$

$$I_{235} = \frac{Z_c + Z_1}{Z_a + Z_c + Z_1 + Z_{235}} = L'$$

$I_2 = nL' \qquad I_3 = mL'$
$Z_{54} = K'\ Z_1$
$Z_{55} = K'\ (Z_1 + Z_c)$
$Z_{56} = K'\ (Z_1 + Z_c) - mL'\ Z_d$

To obtain the constants for load at *6* consider the network as supplying three loads, a positive load at *6*, a positive load at *5* and a negative load at *5*, all loads being numerically equal. First consider a load at *6* fed from *5*. To solve this, mesh *2-1-5* must first be solved alone, giving the value of the impedance from *5* to *2* = Z_{512}. Then, in mesh *5-1-2* with load at *2* fed from *5*,—

$$I_1 = \frac{Z_2}{Z_c + Z_1 + Z_a + Z_2} = m'$$

$$I_2 = \frac{Z_c + Z_1 + Z_a}{Z_c + Z_1 + Z_a + Z_2} = n'$$

$Z_{512} = n'\ Z_2$

Consider mesh *5-3-2* with side *2-5* made up of mesh *5-1-2*. For load at 6 fed from *5*,—

$$I_d = \frac{Z_3 + Z_b + Z_{512}}{Z_3 + Z_b + Z_{512} + Z_d}$$

$$I_{512} = I_3 = \frac{Z_d}{Z_3 + Z_b + Z_{512} + Z_d} = m''$$

$$I_2 = n'\ m''$$
$$I_1 = m'\ m''$$

Superimpose these values on those obtained for load at *5* and the result is obtained for a load at *6* fed from *4*.

$I_1 = K' - m'\ m''$
$I_2 = nL' - n'\ m''$
$I_3 = mL' + m''$
$Z_{64} = (K' - m'\ m'')\ Z_1$
$Z_{65} = Z_{64} + (K' - m'\ m'')\ Z_c$
$Z_{66} = Z_{65} + (K' - m'\ m'' + nL' - n'\ m'')\ Z_d$

The results must satisfy the following equations:—

$Z_{45} = Z_{54}$
$Z_{46} = Z_{64}$
$Z_{56} = Z_{65}$

The above results give self and mutual impedances from *1*. To change these to the values from the source of power add Z_0 to each.

TABLE I—TROLLEY RAIL IMPEDANCES

Trolley Rail Circuit	TROLLEY	TRACKS	TROLLEY	RETURN CIRCUIT		TOTAL IMPEDANCE	
				With Boosters	Without Boosters	With Boosters*	Without Boosters
3-0 Phono, 1-0 Copper, 100 lb. Rail	1	1	0.316 + j0.306	0.092 + j0.211	0.037 + j0.084	0.422 + j0.534 = 0.680	0.353 + j0.390 = 0.526
	1	2	0.316 + j0.310	0.046 + j0.122	0.028 + j0.073	0.376 + j0.449 = 0.585	0.344 + j0.383 = 0.514
	1	4	0.316 + j0.322	0.023 + j0.073	0.016 + j0.051	0.353 + j0.412 = 0.541	0.332 + j0.373 = 0.498
	2	2	0.158 + j0.170	0.046 + j0.122	0.028 + j0.073	0.218 + j0.309 = 0.377	0.186 + j0.243 = 0.305
	2	4	0.158 + j0.180	0.023 + j0.070	0.016 + j0.049	0.195 + j0.267 = 0.330	0.174 + j0.220 = 0.281
	4	4	0.079 + j0.094	0.023 + j0.070	0.016 + j0.049	0.109 + j0.173 = 0.204	0.095 + j0.143 = 0.171
3-0 Phono, 2-0 Copper, 100 lb. Rail	1	1	0.270 + j0.309	0.092 + j0.211	0.037 + j0.084	0.376 + j0.537 = 0.654	0.307 + j0.393 = 0.498
	1	2	0.270 + j0.313	0.046 + j0.122	0.028 + j0.073	0.330 + j0.452 = 0.560	0.298 + j0.386 = 0.488
	1	4	0.270 + j0.325	0.023 + j0.073	0.016 + j0.051	0.307 + j0.415 = 0.515	0.286 + j0.376 = 0.472
	2	2	0.135 + j0.172	0.046 + j0.122	0.028 + j0.073	0.195 + j0.311 = 0.366	0.163 + j0.245 = 0.294
	2	4	0.135 + j0.182	0.023 + j0.070	0.016 + j0.049	0.172 + j0.269 = 0.318	0.151 + j0.231 = 0.276
	4	4	0.068 + j0.095	0.023 + j0.070	0.016 + j0.049	0.098 + j0.174 = 0.199	0.084 + j0.144 = 0.166
3-0 Phono, 3-0 Copper, 100 lb. Rail	1	1	0.232 + j0.312	0.092 + j0.211	0.037 + j0.084	0.338 + j0.540 = 0.634	0.269 + j0.396 = 0.478
	1	2	0.232 + j0.316	0.046 + j0.122	0.028 + j0.073	0.292 + j0.455 = 0.538	0.260 + j0.389 = 0.467
	1	4	0.232 + j0.327	0.023 + j0.073	0.016 + j0.051	0.269 + j0.417 = 0.494	0.248 + j0.378 = 0.452
	2	2	0.116 + j0.173	0.046 + j0.122	0.028 + j0.073	0.176 + j0.312 = 0.358	0.144 + j0.246 = 0.285
	2	4	0.116 + j0.183	0.023 + j0.070	0.016 + j0.049	0.153 + j0.270 = 0.310	0.132 + j0.232 = 0.267
	4	4	0.058 + j0.096	0.023 + j0.070	0.016 + j0.049	0.088 + j0.175 = 0.195	0.074 + j0.145 = 0.162
[illegible] Phono, [illegible] Copper, [illegible] Rail	1	1	0.189 + j0.309	0.092 + j0.211	0.037 + j0.084	0.295 + j0.537 = 0.610	0.226 + j0.393 = 0.452
	1	2	0.189 + j0.313	0.046 + j0.122	0.028 + j0.073	0.249 + j0.452 = 0.515	0.217 + j0.386 = 0.442
	1	4	0.189 + j0.325	0.023 + j0.073	0.016 + j0.051	0.226 + j0.415 = 0.471	0.205 + j0.376 = 0.428
	2	2	0.094 + j0.172	0.046 + j0.122	0.028 + j0.073	0.154 + j0.311 = 0.346	0.122 + j0.245 = 0.273
	2	4	0.094 + j0.182	0.023 + j0.070	0.016 + j0.049	0.131 + j0.269 = 0.298	0.110 + j0.231 = 0.256
	4	4	0.047 + j0.095	0.023 + j0.070	0.016 + j0.049	0.077 + j0.174 = 0.189	0.063 + j0.144 = 0.157
[illegible] Copper, [illegible] Rail	1	1	0.260 + j0.368	0.092 + j0.211	0.037 + j0.084	0.366 + j0.596 = 0.699	0.297 + j0.452 = 0.540
	1	2	0.260 + j0.372	0.046 + j0.122	0.028 + j0.073	0.320 + j0.511 = 0.600	0.288 + j0.445 = 0.530
	1	4	0.260 + j0.384	0.023 + j0.073	0.016 + j0.051	0.297 + j0.474 = 0.558	0.276 + j0.435 = 0.515
	2	2	0.130 + j0.200	0.046 + j0.122	0.028 + j0.073	0.190 + j0.339 = 0.387	0.158 + j0.273 = 0.315
	2	4	0.130 + j0.210	0.023 + j0.070	0.016 + j0.049	0.167 + j0.297 = 0.340	0.146 + j0.259 = 0.297
	4	4	0.065 + j0.109	0.023 + j0.070	0.016 + j0.049	0.095 + j0.188 = 0.211	0.081 + j0.158 = 0.177

*Booster Impedance = 0.014 + j0.017 except 4-Trolleys, 4 Track = 0.007 + j0.009

SHORT CIRCUIT CURRENT IN NETWORK FED FROM TWO SOURCES OF POWER

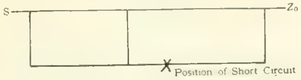


FIG. 9—SHORT-CIRCUIT IN NETWORK FED FROM TWO SOURCES

In Fig. 9—

Z_{xx} = Impedance of point x from primary source of power
Z_{ss} = Impedance of point x from secondary source of power
Z_{sx} = Mutual impedance of points x and s
Z_s = Internal impedance of secondary source of power

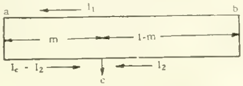


FIG. 10—EQUIVALENT NETWORK OF TROLLEY-TRACK CIRCUIT
For one track of a two track system.

E_o = Generated voltage of primary source of power
E_s = Generated voltage of secondary source of power
I_x = Current at x
I_s = Current from secondary sources
E.m.f. drop from primary source to $x = I_x Z_{xx} - I_s Z_{sx} = E_o$
E.m.f. drop from primary source to $s = I_x Z_{sx} - I_s Z_{ss}$
E.m.f. at $s = E_o - I_x Z_{sx} + I_s Z_{ss} = E_s - I_s Z_s$
$= I_x Z_{sx} - I_s (Z_s + Z_{ss}) = E_o - E_s$

$$I_s = \frac{Z_{xx} (E_o - E_s) - E_o Z_{sx}}{-Z_{xx} (Z_s + Z_{ss}) + Z_{sx}^2} = \frac{E_o Z_{sx} - Z_{xx} (E_o - E_s)}{Z_{xx} (Z_{ss} + Z_s) - Z_{sx}^2}$$

$$I_x = \frac{-E_o (Z_s + Z_{ss}) + Z_{sx}(E_o - E_s)}{-Z_{xx} (Z_s + Z_{ss}) + Z_{sx}^2} = \frac{E_o (Z_{ss} + Z_s) - Z_{sx} (E_o - E_s)}{Z_{xx} (Z_{ss} + Z_s) - Z_{sx}^2}$$

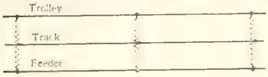


FIG. 11—THREE-WIRE SYSTEM

IMPEDANCE FROM SUBSTATION TO LOAD ON ONE TRACK OF A TWO-TRACK SYSTEM

In Fig. 10—

Z_1 = Impedance of trolley-track circuit for one trolley from a to b.

Z_m = Mutual impedance between trolley wires from a to b

(1) $I_1 Z_1 + (I_c - I_2)\, mZ_1 - I_2 (1\text{-}m) Z_1 = I_1 Z_m - (I_c - I_2) (m Z_m) - I_2 (1 - m) Z_m = 0$

(2) $I_1 Z_1 + I_2 (1\text{-}m) Z_m - (I_c - I_2)\, m Z_m = E_b - E_a$

(3) $E_a - E_c = (I_c - I_2)\, mZ - I_1 m Z_m$

From (1) $I_1 = I_2 - m I_c$

Substituting this value of I_1 in (2) and (3) and solving gives

$E_c = E_a - m (E_b - E_a) + (1\text{-}m) I_c mZ$
$- m (I_c - I_c) - (1 - m) I_c Z_m$

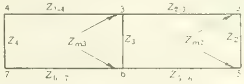


FIG. 12—EQUIVALENT NETWORK FOR THREE-WIRE SYSTEM

THREE-WIRE SYSTEM—EQUIVALENT NETWORK

Consider the network in Fig. 11 as made up of two circuits with self and mutual impedance.

1—Trolley-feeder circuit at double voltage.
2—Trolley-rail circuit at base voltage.

Reduce all impedances to base voltage and let

Z_1, Z_2, etc. be the impedances of the auto-transformers.

Z_{12}, Z_{23}, etc. be the impedances of the trolley-feeder circuit = one-fourth actual impedances.

Z_{52}, Z_{56}, etc. be the impedances of the trolley-rail circuit.

Z_{m1}, Z_{m2}, etc. be the mutual impedances between the two circuits.

The network can then be constructed in the same manner as for the two wire system except that the mutual impedances must be taken into account.

In Fig. 12, consider mesh *3-4* with unity load at *7* fed from *3*.

(1) $I_4 (Z_{34} + Z_4) + I_4 \frac{Z_{m3}}{2} = I_3 (Z_3 + Z_{67}) + I_4 \frac{Z_{m3}}{2}$

(2) $I_3 + I_4 = 1$

From which

$$I_3 = \frac{Z_{34}\, Z_4 - \frac{Z_{m3}}{2}}{Z_3 + Z_4 + Z_{34} + Z_{67} - Z_{m3}}$$

$$I_4 = \frac{Z_{67}\, Z_3 - \frac{Z_{m3}}{2}}{Z_3 + Z_4 + Z_{34} + Z_{67} - Z_{m3}}$$

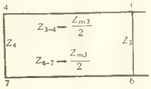


FIG. 13—SIMPLE TWO-WIRE NETWORK

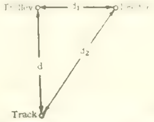


FIG. 14 RELATIVE LOCATIONS OF TROLLEY, TRACK AND FEEDER

Consider load at 6 fed from *3*.

(1) $I_4 (Z_{34} + Z_4\, Z_{67} - \frac{Z_{m3}}{2} - \frac{Z_{m3}}{2}) = I_3 Z_3$

(2) $I_3 + I_4 = 1$

$$I_3 = \frac{Z_{34} + Z_4 + Z_{67} - Z_{m3}}{Z_3 + Z_4 + Z_{34} + Z_{67} - Z_{m3}}$$

$$I_4 = \frac{Z_3}{Z_3 + Z_4 + Z_{34} + Z_{67} + Z_{m3}}$$

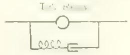
The values of I_3 and I_4 are exactly the same as if the network were as shown in Fig. 13.

This is a simple two wire network. For calculation of self and mutual impedances, the network with mutual impedance should be used, but for calculation of distribution currents the simple network is applicable.

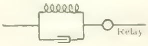
In the above Z_m is calculated as equal to the resistance of the trolley + j (Reactance of trolley with respect to track + mutual reactance of feeder with respect to trolley-track.) Reactance of trolley with respect to track = $0.116 \log \frac{d}{0.78r}$ for 25 cycles. Mutual reactance of feeder with respect to trolley-track = $0.116 \log \frac{d_1}{d_2}$ for 25 cycles, when the distances d, d_1 and d_2 are as represented in Fig. 14.

APPENDIX B

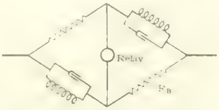
RESONANT SHUNTS FOR TELEGRAPH CIRCUITS



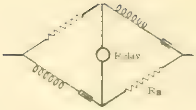
I. Circuit in series resonance shunted around relay. This forms a low resistance path for the induced voltage of railway frequency. By the use of a commercial retardation coil and 6 m. f. of condensers very good telegraph operation has been obtained with an alternating current voltage of four times the direct current voltage.



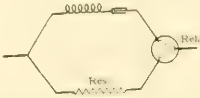
II. Circuit in parallel resonance in series with relay with same coils and condenser as used for I; this has been effective with an alternating current voltage equal to the direct current voltage.



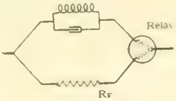
III. Parallel Resonant Bridge. R_B = Resistance of resonant bridge arm at railway frequency. An improvement over II but has not proved to be as good as I.



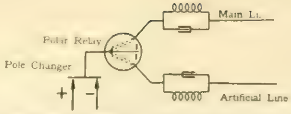
IV. Series Resonant Bridge. R_B = Resistance of resonant bridge arm at railway frequency. Results show an improvement over I.



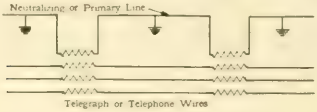
V. Differential Relay. Special double winding relay. Alternating current divides evenly in windings. The direct current flows only in the resistance side.



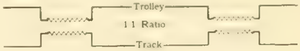
VI. Differential Relay with parallel resonance. R_F = Resistance of resonant circuit at railway frequency.



VII. Paralleled Resonant Circuit for duplex working.

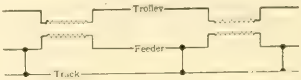


VIII. Neutralizing Transformer System. Neutralizing wire runs among tel. wires and is subject to the same induction.



IX. Track Booster Transformers.

Current in track = current in trolley — magnetizing current of transformer. E. M. F. across transformer = impedance drop in rail section in which it is connected.



X. Feeder Booster Transformer.

Safety-First Testing of Small Transformers

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Assistant Works Electrical Engineer,
Westinghouse Electric & Mfg. Company

The testing of electrical equipment may be divided into two broadly different classes. New equipment is given a complete engineering test to determine fully the characteristics of the apparatus. Such tests are intended for the benefit of the engineer who designed the equipment, and the data so obtained is of great importance in assisting him in checking up his design and perfecting details. As such tests are usually made but once for each different design, rapidity of testing is not essential.

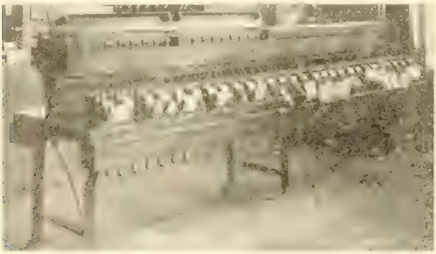

FIG. 1—SAFETY FIRST BOTTLE TEST RACK

The routine, or quantity testing of the equipment, while less important from the purely design standpoint, is much more important from the production standpoint. Prompt deliveries to some extent depend on the time required by the tester to satisfy himself, the designing engineer, and the customer that each piece of apparatus will meet the specifications. The tester's report is practically the only check on the quality of the workmanship in the factory. Because certain types of apparatus pass through the factory in large numbers, the importance of this testing, and the necessity for get-

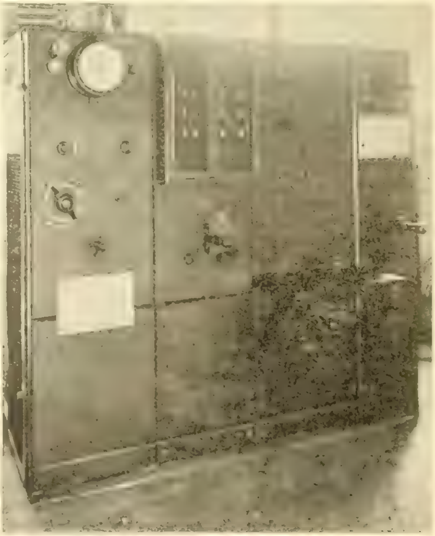

FIG. 2—TEST BOARD FOR SMALL TRANSFORMERS

ting it done quickly and at the least possible expense, warrant the installation of equipment intended primarily to facilitate rapid and accurate results.

In the construction of such equipment the human element must be carefully considered. Both from the standpoint of eliminating accidents and of increasing the rapidity of testing, it is found that the equipment must be thoroughly safe-guarded. Hence, in building special testing outfits, the principle of "safety first" must be kept prominently in mind, as otherwise the tester soon comes to realize the danger to which he is daily exposed, causing him to become dissatisfied with his work, and thus interfering with production. Modern testing equipment is, therefore, so designed that it is practically impossible for the tester to expose himself to a live circuit, no matter how careless he may be.

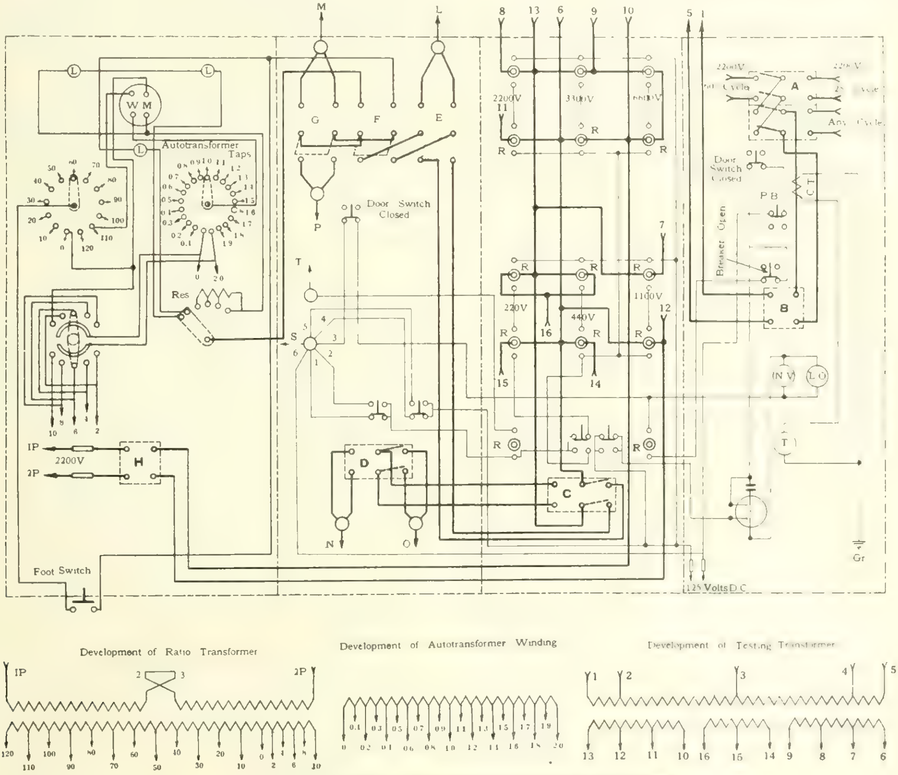

FIG. 3—WIRING DIAGRAM OF TEST BOARD SHOWN IN FIG. 2

An example of modern equipment for testing small shunt transformers is shown in Figs. 1 and 2. The test board consists of four panels, Fig. 2, counting from right to left. Panel *1* controls the primary side of the testing transformer or the transformer supplying the current used in performing the various tests. Panel *2* controls the secondary side of the testing transformer. Panel *3* controls the primary and secondary switches making connections with the double test rack and controls also the supply current for the ratio board. Panel *4* is the ratio board used to take the ratios of the transformers under test. The double test rack, Fig. 1, completes the testing equipment which meets all requirements for testing small shunt or potential transformers.

The wiring diagram for the test board is shown in Fig. 3. The power for the testing transformer is supplied to the oil circuit breaker *B*, through the double two-pole double-throw oil switch *A*, through which 2200 volts at 60 cycles, or any frequency or voltage that is available on the test floor, is supplied over a relay circuit connected to the main power distribution board. The 220, 440, 1100, 2200, 3300 and 6600 volt taps of the testing transformer secondary are connected to the 12 plug receptacles *R* mounted on panel *2*. By plugging into the receptacles, the secondaries of the testing transformer are connected to the two-pole double-throw oil switch *C* mounted on panel *2*. Moving the handle of the oil switch to the up position connects the receptacles with the two-pole double-throw oil switch *D*, mounted on panel *3*, which controls the two primary busses of the double test rack. Moving the handle of the oil switch *C* to the down position connects the receptacles to the two-pole double-throw knife switch *E*, mounted on panel *3*, which controls the secondary windings of the ratio transformer. The primary side of the ratio transformer is connected across a 2200 volt tap of the secondary side of the testing transformer through the fused two-pole oil switch *H*. The secondary side of the ratio transformer has 12 ten volt taps and 5 two volt taps. The ten volt taps are connected to the dial switch mounted on the upper left hand side of the ratio board and the two volt taps are connected to the transfer dial mounted on the lower left hand side of the panel. The transfer dial switch connects a two volt autotransformer with 20 one-tenth volt taps across any of the two volt taps of the ratio transformer. With the three dial combinations, any voltage ranging from 0.1 of a volt to 130 volts can be had. The rheostat switch, mounted on the lower right hand side of this panel, controls the pilot and polarity lamps *L* on the first point. As the arm is moved to the right it cuts out resistance in circuit with the series coils of the ratio meter. This resistance protects the ratio meter when there is a great difference of potential between the transformer on test and the ratio transformer. The ratio meter is a single-phase wattmeter with 110 volt shunt coils and 2.5 ampere current coils. The scale or dial of the wattmeter was changed to a differential scale marked high and low with a zero point as a point of balance. The secondary side of the ratio transformer is connected through a floor switch, to the two-pole double-throw knife switch *E*, which is mounted on panel *3*. Through this knife switch the secondary side of the ratio transformer can be connected to either secondary bus of the double test rack. Should the tester forget to open the oil switch *H*, controlling the primary side of the ratio transformer, the secondary side of this transformer is opened automatically by the floor switch as the tester steps away from the ratio board. The primary side of the ratio transformer is opened through the circuit breaker *B*, on the primary side of the testing transformer, which is controlled by the interlocks on the gates guarding the handles of the spring connectors on the primary bus of the test rack.

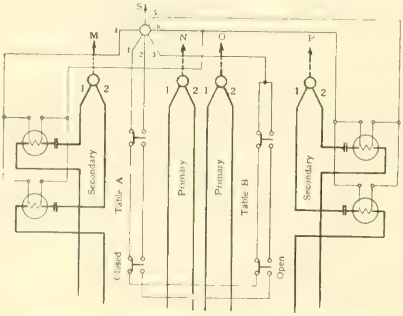

FIG. 4—WIRING DIAGRAM OF DOUBLE TEST RACK

A wiring diagram for the double test rack is shown in Fig. 4. The primary busses are mounted on the top section of each side of the rack and are guarded by bakelite boards which are provided with holes through which the primary leads are connected to the busses by means of spring contacts which are operated by insulated handles. These handles are guarded by a two section gate which operates the interlocks mounted on both ends of the test rack. The secondary busses are mounted on the lower section of the test rack and are guarded in the same way as the primary busses with the exception of the gates.

Transformers cannot be tested on both sides of the test rack at the same time; while one side is being used for testing, the transformers on the other side of the rack may be disconnected and removed, after test, or another batch of transformers can be connected and made ready for test. In order that no power may be thrown on the side of the rack on which the transformers are being connected or are being removed, after completion of test, the gates on that side of the rack, which control the interlocks on the gates on the opposite side of the test rack, must be thrown in the open position. Should the tester fail to open these gates he will not be able to connect power to either side of the test rack.

The "Safety First" features of this test board consist in the following devices:—

1—A current trip and a no-voltage release and lockout device controls the oil circuit breaker *B*, mounted on panel *1*, controlling the primary side of the testing transformer.

2—An interlocking system by which all plug receptacles, oil and knife switches on panels *2* and *3*, the doors leading to back of switchboard and knife switch panel, and the gates guarding the insulated spring contact handles connected to the secondary busses of the test rack are interlocked with the no-voltage release and lockout device controlling the main oil circuit breaker.

3—Timing devices mounted in the plugs which cause the main circuit breaker to kick out before the contacts carrying high potential power can be opened.

The interlocking system holds the main oil circuit breaker in the lockout position when:—

1—The tester forgets to close the guard gates of the test rack.

2—The plugs have not been properly inserted in the receptacles.

3—The knife switch panel door on panel *3* or the doors leading back of test board have been left open.

4—The tester has failed to open the gates on the opposite side of test rack.

The main oil circuit breaker is kicked out automatically when:

1—The tester forgets to kick out the circuit breaker before opening the guard gates on the test rack.

2—The tester attempts to remove a plug from a receptacle in order to change the secondary connections on the testing transformer while the circuit breaker is closed.

3—Too heavy a current is drawn from the testing transformer.

The receptacles are interlocked as shown in Fig. 3. When the two plugs are properly inserted, the interlock circuit is closed, lifting the no-voltage release and lockout device clear off the closing mechanism of the main oil circuit breaker *B*. By removing one of the plugs from the receptacle the interlock circuit is opened by the timing device which will kick out the main circuit breaker and lock out same in the open position before the high potential current carrying contacts are opened.

Moving the handle of the oil switch *C* to the up position, closes the interlock of this oil switch with the interlocks of the plug receptacles controlling the voltages from 440 to 6600 volts respectively. Moving the handle down closes the interlocks on this oil switch with the interlocks of the plug receptacles controlling the 220 volt tap on the secondary side of the testing transformer. The two receptacles mounted on the sides of the oil switch, as shown in Fig. 3, are used for the storage of the plugs when the test board is not in service. The interlocks of these two receptacles are interlocked with the no-voltage release and lockout device mounted on the oil circuit breaker of the power supply circuit. The oil switch *D* controlling the primary busses of the test rack and the secondary switches of the ratio-board are interlocked with the interlocks of the oil switch and with the interlocks controlling the gates of the double test rack.

Summing up the "Safety First" features of this testing equipment, it will be noticed that the interlocking system not only protects the tester, by preventing him from making a wrong move which might cause him or others serious bodily injury; but it also prevents the destruction of the equipment itself, and thus unnecessary delays in promised deliveries.

The Choice of Instrument Transformers

L. Dorfman

THE PROBLEM of choosing suitable instrument transformers is not always as simple as it might seem. In fact, the things which may be desirable and essential in one application may be of small moment in another case. Instrument transformers are of two kinds, potential or shunt transformers, and current or series transformers. As the name implies, a potential transformer is used to step down the voltage to a safe and convenient value. The purpose of a current transformer is in some cases merely to transform a large value of current to a lower, convenient value, while in other cases, it is not intended to change the current value at all, but its purpose is to prevent contact with the high voltage line. In many cases, the current transformer serves a double purpose, namely; to prevent contact with a high voltage line and also to reduce the current to a low convenient value. The use of instrument transformers also reduces the range of voltage and current for which instruments must be designed.

POTENTIAL TRANSFORMERS

A potential transformer should be chosen with two ideas in view. First is the quality of insulation. In other words, the question of safety, both to the instrument man and to the system, must have chief consideration. Second, the accuracy of transformation under varying loads (generally spoken of as performance) must be considered. In addition, when the transformer is to be used for continuous service on a system where surges are apt to occur, it should be insulated sufficiently so that surges, or other disturbances, will not cause a breakdown, and thus cripple the service. Extra protection against surges is usually obtained by the introduction of choke coils in the cases of higher voltage. Low voltage systems are generally not of sufficient extent to make surges of much consequence. However, even in the lower voltage cases, ample extra insulation is provided to take care of any disturbances that may occur. It requires no very great stretch of the imagination to see that, unless the potential transformer is well chosen and properly installed, it may be the weak spot in the whole system. Due to the fact that fusing alone, in the case of potential transformers, does not offer the proper protection, current limiting resistors are generally used in series with the transformer primary. This limits the energy which would go into a short-circuit in the potential transformer circuit and hence reduces the possibilities of serious trouble. In addition, it is highly desirable to place the potential transformer in a cell or other suitable compartment in order to isolate any trouble which might possibly develop. It is evident from the above that a slightly greater cost in the potential transformer and its installation may well be a profitable investment, being, in fact, good insurance.

The question of accuracy in potential transformers is one which depends almost solely on the purpose for which it was designed. If the transformer is to be used for experimental or research work, where accuracy is essential, then a transformer having good performance is desirable. Furthermore, ratio and phase-angle curves for the transformer should be available for making corrections. A comparatively high degree of accuracy is unnecessary in other cases, except where it is used with watthour meters. This is evident when it is remembered that even a small error is accumulative and may become appreciable in a reasonable length of time. It is usually advisable to have the watt-hour meter calibrated with the transformer. Where indicating instruments are connected to the transformer, no very great accuracy is essential because the accuracy of reading the instrument may vary at least one percent.

CURRENT TRANSFORMERS

Practically all of the conditions which have to be met in the application of potential transformers must likewise be provided for in the case of current transformers. In addition, the current transformer generally must meet other severe requirements. This should be apparent when it is remembered that the potential transformer usually isolates itself if trouble develops. On the other hand, since the current transformer must of necessity be connected directly into the line, it is compelled to take the consequences whatever they may be. Now in the case of severe short-circuits, the current transformer must stand up to the job. Unless the current transformer is capable of doing this, then it is a weak spot in the system. The consequences of this weakness may be just as serious as they could be in any potential transformer failure. In fact, the chances are that they may be far more serious in most cases, because usually the trouble cannot be isolated without a discontinuance of service. Translated into mechanical characteristics, this means that the transformer must not only be exceedingly well insulated, but it must be capable of withstanding the severest short-circuit stresses that may occur. A poorly designed current transformer may tear itself apart when a short-circuit occurs due to the large mechanical stresses developed. In order to successfully withstand short-circuit stresses the transformer coils should be eleptical or circular, and should be well braced to prevent movement. The current transformer should be especially well insulated for the reasons mentioned above. The insulation must be amply sufficient to withstand the voltage to ground and should be capable of taking care of surges, etc. A margin should be allowed to insure against discontinuance of service. In addition, the current transformer should be capable of withstanding considerable overloads for reasonable lengths of time without overheating. In this respect, it should be designed to carry the same overloads as the rest of the apparatus. The matter of desirable accuracy is the same as in the case of potential transformers.

GENERAL CONSIDERATIONS

In addition to the above qualifications, instrument transformers should be readily adaptable to the general layout. Such factors as adaptability, appearance, ruggedness, etc., are matters that should not be entirely overlooked. A current transformer of the through type, i.e., one in which the terminals are placed diametrically opposite, lends itself well to general switchboard practice. This applies of course primarily to the lower voltage, dry-type transformers.

The Induction-Type Frequency Changer

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Westinghouse Electric & Mfg. Company

IT SOMETIMES HAPPENS that electrical energy is desired at some frequency other than that of the available supply. The object may be to control the speed of some motor by varying the applied frequency; it may be to obtain a higher frequency simply to be able to drive two-pole motors at higher speeds than would be otherwise possible; or, it may be to obtain low frequencies in order to be able to operate some kind of mechanical vibrator. So far, the only means of obtaining this change in frequency has been through special rotating apparatus, i.e.—a motor-generator set, a motor-converter set (commutator machine), or an induction-type set.

An induction-type frequency changer set usually consists of two machines, one of which is very similar, if not exactly like, a standard wound-rotor polyphase induction motor; the other machine may be either an alternating-current or a direct-current machine, and may function either as a motor or as a generator, depending upon the arrangement of connections used. The member first mentioned, having the wound rotor, is the frequency changer part of the set. The second member serves to determine the operating speed of the frequency changer, and incidentally to supply or take mechanical power from it over the common shaft.

The induction-type changer is successfully used where the power at the new frequency is comparatively small, and where the voltage regulation of from 10 to 15 percent resulting from such a machine is not objectionable. Successful applications exist in several industries where motor speeds of from 5000 to 18000 r.p.m. can be used advantageously. Today high speed motors are applicable, as a component part of the apparatus, to internal grinding machines, separators and centrifugals, sensitive drills, as well as shapers, surfaces, planers and many other wood working machines. These are driven by small two-pole motors and, of course, require higher frequencies than 60 cycles. Close voltage regulation is not important for two reasons; first, because the two-pole motors have naturally high pull-out torques, and second, because a part of the drop in voltage is accompanied by a drop in frequency. This latter characteristic helps to maintain a stiff pull-out torque. Another case to be considered is where a lower frequency is required to operate solenoids in vibrating machinery.

Usually the amount of power used in the above application would warrant buying an induction-type set rather than a standard alternating current to alternating current motor-generator set. Because, for example, where 100 kw is required, the latter set would consist of two 100 kw machines; whereas, in some cases, if an induction-type set is used the machines need be only 50 kw each. This would be true where the change was from 60 to 120 cycles. Where the driving motor is a squirrel-cage motor, the set would be less complicated. Another reason for the use of this type is the fact that practically standard industrial motors can be used.

THEORY OF OPERATION

The purpose in the following paragraphs is to give a simple, easy-to-grasp explanation of the fundamentals of operation of such a machine an explanation complete in itself. As a secondary purpose it is to suggest possibilities of further theory and applications, to those interested enough to explore beyond the scope of this article.

When the rotor of an induction motor is revolving at synchronous speed, the frequency and voltage of the secondary circuit is zero; because the rotor conductors are moving across the stator core teeth at the same speed as the rotating magneting field, and hence are stationary in that field. However, if the rotor is held at a speed somewhere below synchronism, or rotated above synchronism, the voltage and frequency of the rotor will take a value which increases directly as the difference between the rotor speed and the synchronous speed. If the rotor be locked, the secondary frequency is the same as that of the primary, and the voltage is equal to that of the primary multiplied by a ratio of transformation. Rotating the secondary against the rotating magnetic field of the primary will, of course, produce a higher voltage and a secondary frequency greater than that of the primary circuit.

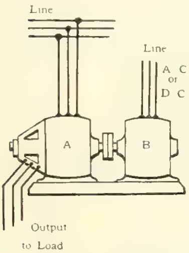

FIG. 1—ARRANGEMENT OF INDUCTION TYPE FREQUENCY CHANGER SET

The arrangement pictured in Fig. 1 is the one usually employed, especially where the generated frequency is to be greater than that of the supply. Assuming 60 cycles supply and that the rotor is being driven against the rotating magnetic field so as to generate 120 cycles at the rotor rings; a good idea of the path, direction of flow, and distribution of power flowing through the set can be secured from Fig. 2.

Fig. 3 represents another way of observing what is going on inside the wound-rotor machine. The vectors representing the rotor circuit are values which are the primary equivalents of the secondary. In other words, the ratio of the turns in the secondary winding to the turns in the primary winding is assumed to be 1 to 1. The symbols represent values as follows:—

E_1 = The full primary line voltage.

E_2 = The secondary voltage under locked condition.

$E_2\ (S\text{-}1)$ = That part of the voltage generated in the rotor which is due to the counter rotation, when the rotor is driven backward.

$SE_2 = E_2 + E_2\ (S\text{-}1)$ = The total voltage generated in the rotor windings by the magnetic field.

E_{sec} = The resultant terminal voltage of the secondary after the resistance and reactance drops are subtracted.

I_2 = The secondary current.

I_1 = The primary current.

I_0 = The no-load current in the primary.

I_m = The magnetizing current in the primary.

I_p = The power component of the primary no-load current.

S = The slip, or the ratio

$$\frac{\text{Synchronous r.p.m.} - \text{Running r.p.m.*}}{\text{Synchronous r.p.m.}}$$

r_1 = The resistance of the primary.

r_2 = The resistance of the secondary.

X_1 = The reactance of the primary.

X_2 = The reactance of the secondary.

θ = The angle of lag of the output current behind the voltage generated in the secondary.

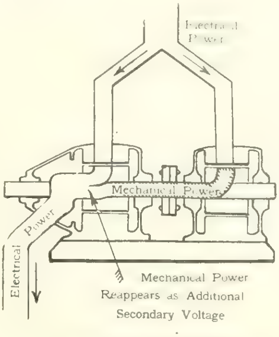

FIG. 2—DISTRIBUTION OF POWER FLOWING THROUGH SET

For convenience, consider all the symbols as representing values limited to one internal phase of a three phase machine. The total power generated within the secondary winding is $3SE_2I_2cos\theta$, and this is divided into two parts: first, that which is generated by the movement of the primary flux, and which comes through the primary winding, $3E_2I_2cos\theta$; and second, that which is due to the counter rotation of the shaft, and which is equal to $3E_2(S\text{-}1)I_2cos\theta$. This second component of the power simply grows out of the increase in voltage over the locked voltage, and is supplied by the driving-motor B, which furnishes this power by rotating the shaft against the resisting forces which must necessarily exist between the stator flux and the rotor current. Another way of stating the same is as follows:

$$\begin{array}{c}\textit{Input by the}\\ \textit{driving motor}\end{array} = \frac{S\text{-}1}{S}\left(\begin{array}{c}\textit{Watts Output}\\ \textit{plus}\\ \textit{Sec. Copper}\\ \textit{Losses}\end{array}\right) + \left(\begin{array}{c}\textit{Rotating}\\ \textit{Losses of}\\ \textit{Frequency}\\ \textit{Changer}\end{array}\right)$$

Of course the secondary copper losses and the rotating losses are both small and may be omitted where the motor applied is ten percent higher in rating than the horse-power calculated.

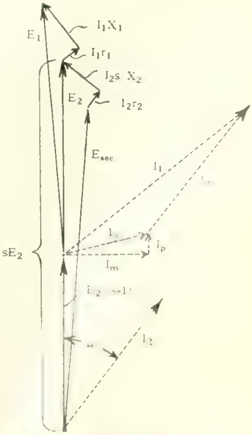

FIG. 3—VOLTAGE AND CURRENT VECTORS FOR WOUND ROTOR MACHINE

The chart Fig. 4, shows in a graphical way the different capacities which a given set may possess if driven at various speeds. The conditions are:—(1) a connection as shown in Fig. 1, (2) constant primary voltage and constant current values, (by the latter is meant that the copper windings are subject to the same current densities) and (3) it is assumed that B is an adjustable speed machine. It is of course only approximate, because of the variation of the secondary iron losses as the speed is varied.

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*(NOTE—r.p.m. against the rotating field is to be considered negative.)

In discussing this chart, it is necessary that the two machines of Fig. 1 be kept in mind. To the left of the vertical line indicating zero speed, *B* acts as a motor, and drives *A* against its rotating magnetic field, thus producing a frequency above the standard line frequency. The power from the line is flowing toward the set in the case of both machines, and the total capacity of the set need only be that equal to the output from the secondary leads. This condition is good, and makes better use of the material in the set than certain other conditions do as will be shown later.

Between zero speed and the normal synchronous speed of the frequency changer, this machine is operating as a motor and driving *B* as a generator; and in this way *A* receives, not only all the power output, but also the power imparted to *B* and thence back to the line. The flow of power is from the line to *A*, and from *B* to the line. The low frequency output receives only the difference. You can see that this condition is not economical in the employment of the material.

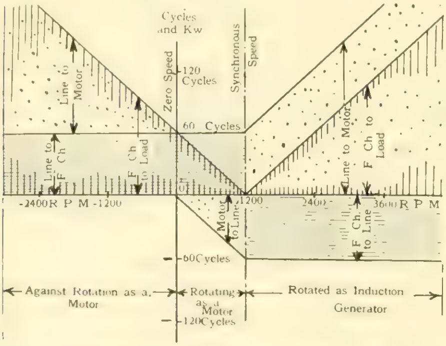


FIG. 4 — CAPACITIES OF SET AT VARIOUS SPEEDS

When *A* is driven above synchronism, the conditions are represented to the right of the line marked *Synchronous Speed*. Here the wound rotor machine serves as an assynchronous generator, and the power flows from the line to the motor *B*, and some of it from the generator back to the line. Again, the secondary gets only the difference.

The following simple formula may prove convenient. Where r.p.m. means the operating speed of the set, and synchronous speed designates the synchronous speed of the wound rotor machine as a motor. f_1 is the line frequency, and f_2 is the output frequency.

Driving against the magnetic field:—

$$f_2 = f_1 \left(\frac{r.p.m.}{Synchronous\ speed} + 1 \right)$$

$$r.p.m. = \left(\frac{f_2}{f_1} - 1 \right) Synchronous\ speed$$

Driving with the magnetic field:—

$$f_2 = f_1 \left(\frac{r.p.m.}{Synchronous\ speed} - 1 \right)$$

$$r.p.m. = \left(\frac{f_2}{f_1} + 1 \right) Synchronous\ speed$$

When two machines of a set are direct connected, no matter what may be the speed or the secondary frequency, the full-load torques of the two machines must be the same; and hence the machines must be of approximately the same weight. Where ventillating conditions are similar, it takes approximately the same weight of copper and iron to produce a given full-load torque in one commercial motor as in any other; unless it be a single-phase machine. Of course there are many cases where it may be desirable to belt the two machines together. Where the speed of the wound-rotor machine is low, the machine *B* may be much cheaper if a high speed unit can be used.

The arrangement shown in Fig. 5 is applicable where a lower frequency is to be generated, and is a good substitute for the connection in Fig. 1. This comes from the fact that the power flows only one way through the set, and that is toward the output end; which of course makes it a desirable set-up. *A* and *B* represent a simple concatenated set, with a tap run from the secondary leads from which to draw power. The machine *A* really functions as a motor, driving *B* as an induction generator; and the power flows as indicated by the arrows. A peculiar thing about the slip is that as the load comes on, the speed of the set rises instead of drops, and the secondary voltage and frequency drop as the result. The regulation should be only a few per cent. The same rules govern the operating speed of such a set as govern cascade motor sets. The resultant synchronous speed is the same as that of a motor having a number of poles equal to the sum of the poles of the two machines. This applies to the condition of direct cascade, or where both machines tend to start in the same direction. For differential cascade, or where the machines tend to start in opposite directions, the resultant speed is the same as that of a motor having a number of poles equal to the difference of the poles of the two machines used. The latter set is not self-starting, and is of little use in this application.

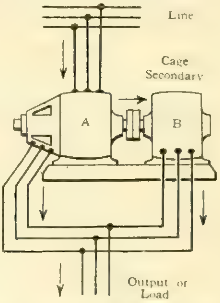


FIG. 5 — ARRANGEMENT FOR GENERATING A LOWER FREQUENCY

Ventilation and Temperature Problems

In Large Turbogenerators—(Concl.)

B. G. LAMME

VENTILATION AND TEMPERATURE PROBLEMS OF THE ROTOR

The actual copper loss in the rotor may be as much as 80 to 100 kw, and most of the heat resulting from this must be radiated from the rotor air-gap surface. In addition there are eddy current losses in the rotor iron, sometimes relatively large, due to the open stator slots, etc. And yet the excitation, or copper losses in turbo-alternators are very small, in percent, compared with other types of rotating electrical machines. In a 30 000 kw, turbo-alternator, one-quarter of one percent, expended in the exciting windings, means 75 kw loss in the rotor, which must be dissipated. The rate of heat dissipation from the gap surface of the rotor is often extremely high. Four to five watts per square inch of gap surface is not unusual. Comparing this with the 0.5 to 1.0 watt per sq. in. common in connection with dissipation of the excitation heat in more moderate speed machines, it may be seen that the above figures indicate a very abnormal rate of heat dissipation to air.

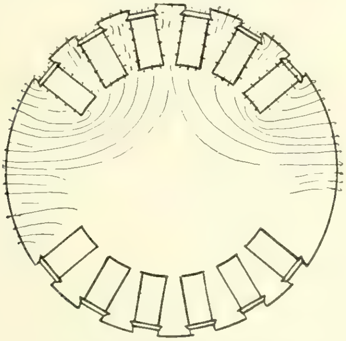


FIG. 9—MAIN PATHS OF HEAT FLOW
In radial slot two-pole rotor

The writer believes he was one of the first to use purely air-gap ventilation for the cooling of high-speed turborotors, and his early tests gave decided evidence of the great effectiveness of this method. However, there is naturally a limit to the effectiveness of such cooling, for there is some point where the improvement is quite small, with materially increased air velocities. Possibly air "cavitation" comes in, as one of the conditions which influence this result. The effectiveness of the air, in cooling the rotor, depends upon the scouring action of the air on the rotor surface, the hot layers in contact with the metal being continually torn off and replaced by cooler air. Experience shows that this action does not appear to be proportionally effective with air velocities above a certain amount. Apparently the ventilating air along the air-gap is crowded out against the stator surfaces, and thus possibly may become more effective in cooling the stator, with the higher velocities. Under such conditions, sinking the stator coils well below the gap surface should be especially beneficial.

Fig. 9 illustrates the arrangement of the rotor coils and core, in cross-section, in the usual radial slot two-pole rotor. There are two main paths of heat flow from the rotor coils, namely, outward directly toward the surface, and inward to the central body or core and then along the metal of the core to the pole surface and to the ends of the core. Obviously these latter paths are very much longer than the former, but to compensate for this, their sections are relatively larger, so that the density of heat flow is correspondingly lower.

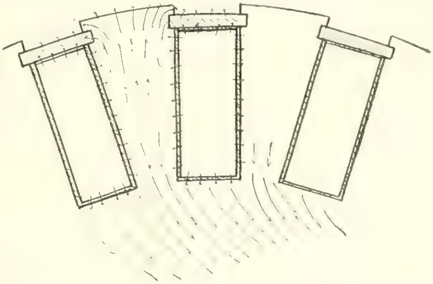


FIG. 10—DIVISION OF HEAT FLOW FOR INDIVIDUAL ROTOR SLOT AND ITS WINDING

Consider an individual rotor slot and its winding, as shown in Fig. 10. Here the first temperature drop of importance is from the copper to the surrounding iron, and the supporting wedges. The amount of drop is dependent upon the density of heat flow, thickness and grade of insulation, etc. The division of heat flow between the direct outward path and the various inward paths is dependent upon the relative heat conducting characteristics of these paths, as determined by their lengths, cross-sections, materials, etc. The problem of the heat flow and distribution is somewhat similar to that of the axial type of stator, except that it is more complicated.

In the end windings of the radial slot type of rotor, still other problems of ventilation and heating are encountered. The usual arrangement of the end windings, Fig. 11, shows six slots per pole. Here the end windings are exposed to the air, and should show ideal conditions for ventilation, provided good air circulating conditions are obtainable. A heavy supporting end ring is required over the windings, and the coils must be well insulated from this. This enclosing ring is a direct hindrance to radial ventilation between the coils. Numerous ventilating holes through the supporting ring will aid, but this in turn brings up problems of surface leakages and creepage distances, especially where the end windings have no outer wrappings, which is frequently the case. Outer wrappings over these end windings tend to bulge and crush out of shape, collect dirt, etc., and, in consequence, some manufacturers omit them altogether, and more or less completely enclose the end windings, except from below, believing that better insulating conditions can be obtained in this manner. To compensate for the reduced ventilation of the windings, it is not unusual to arrange ventilating channels into and through the rotor core, directly under the rotor coils, as shown in Fig. 12, fifteen suitable radial outlets being supplied near the core center.

IRON LOSSES IN TURBOGENERATORS

The stator or armature core losses in large turbogenerators follow the same laws as in other types of rotating apparatus, (except possibly in degree) due largely to the abnormal magnetic proportions. In the largest synchronous converters, outputs of 300 kw per pole are considered quite high; in large high-speed waterwheel generators, synchronous condensers, etc. 3000 kw or kv-a. per pole is unusual; but, in modern capacity turbo-alternators, 8000 to 10 000 kv-a. per pole is accepted practice for 60 cycles, and up to 20 000 kv-a. per pole for 25 cycles. Such enormous outputs per pole can only mean abnormal magnetic proportions, compared with other classes of electrical apparatus. In consequence, special problems are encountered, in the way of losses, both in the iron and in the copper parts.

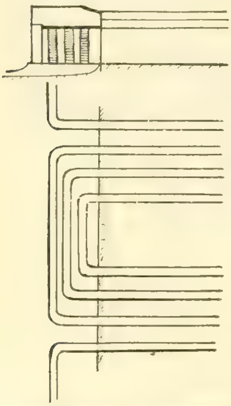


FIG. 11—USUAL ARRANGEMENT OF END WINDINGS

One of the special conditions is the relatively high voltage between laminations, compared with ordinary types of machines. For comparative purposes this may be expressed in terms of volts per inch of core. In ordinary types, one volt per inch width of core is quite high, whereas in some of the modern turbo-alternators this figure is doubled, or even more in some instances. This, together with the enormous plate surface per pole, tends to exaggerate eddy current losses in the iron. The laminae must be insulated from each other, better than in ordinary machines. The effects of the burred edges of the plates, due to punching, are more pronounced. For instance, a two-mil (0.002 inch) burr is considered quite small in punching, yet with 17 mil plates, this burr represents about 12 percent of the plate thickness, and several times the depth of the insulating coating on the plates. Such burrs, under great pressure, tend to cut through and make metallic contact between plates. Such minute contacts may seem to be of minor importance. But in the huge turbo-alternators, with their high voltages between plates, the effects of undue burr are quite considerable.

In the same way, extreme care must be taken to line up the stator plates or punchings, so that little or no filing is necessary in the coil slots. If the building is uneven, so that individual laminae project into the slots, these high points should be removed, otherwise the coils are liable to loosen in the slots in time, through concentrated pressure, with consequent wear of the insulation at the projecting laminae. On the other hand, if one attempts to level down the high laminae by filing, as has been not uncommon practice in other types of machines, there is more or less danger, due to possible dragging over of adjacent laminae, with consequent metallic contact.

Apparently, pressure has a considerable effect on the losses in turbogenerator cores, possibly due to the establishment of better contact between adjacent plates, the burr cutting through the insulating coating on the plates. Quite often, in assembling the stator core, the resulting pressure is greatest next to the ends and, in practice, greater losses and higher temperatures have resulted. To lessen the loss, by breaking up the contact between plates, etc., it is sometimes the practice to add separating sheets of suitable paper at frequent intervals throughout the core, the intervals being shortened near the core ends. This has proven quite effective in equalizing the losses and temperatures due to core pressure. In one case where the core losses were unduly high, and there was excessive temperature in the end sections, the writer had the stator iron removed for about six inches, at each end, and then replaced, adding sheets of fairly heavy "express" paper every ⅛ inch. With the original amount of iron replaced in the core, thus representing greater compactness and higher pressure than before, the stator losses were down to normal, and the temperatures were well equalized.

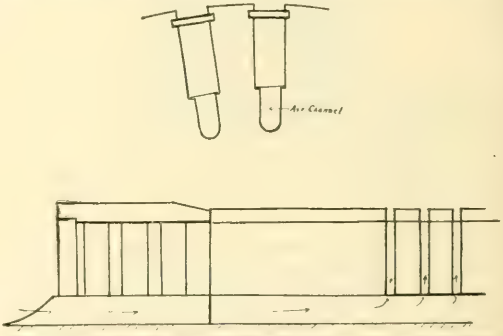


FIG. 12—AXIAL AND RADIAL VENTILATING CHANNELS IN ROTOR CORE

While the effect of the punching of the plates is to produce burrs, which may be eliminated to a great extent by further treatment, it also has a harmful effect in increasing the magnetic losses in the iron, apparently due to the shearing effect. The action of punching or shearing seems to affect the material in proximity to the sheared edges. Consequently the harmful effect is largest, where the sheared edges bear a high ratio to the total iron, that is, at the teeth. Annealing after punching may often show a gain sufficient to warrant the additional expense.

ARMATURE COPPER LOSSES IN TURBOGENERATORS

Like the iron losses, the armature copper losses follow the laws of ordinary machines, except in degree. There are three principal losses to be considered,—(1) the usual C^2R due to the load current, (2) eddy currents in the conductors due to the flux across the armature slots set up by the armature load current, and (3) the eddy currents in the coils set up by the main field, or gap, flux entering the top of the armature slots. Loss (1) is taken care of by a suitable section of conductor. Loss (2) may be quite large in large turboalternators, due to the fact that the ampere-wires per slot are quite large in many cases, the number of slots being small due to the physical limitations of the dimensions of the machines. This means relatively deep slots and coils, and a tendency for excessive local currents, unless unusual sub-division or lamination of the conductors is resorted to, this being done quite completely in modern practice. Loss (3) due to gap or field flux penetrating the slot and armature conductor is dependent upon the amount of such flux, which in turn depends upon the proportions of the slot with respect to the gap, etc. At first glance, one would be inclined to say that, with a small air-gap, the gap flux would penetrate the armature slot more than with a wide gap but, in fact, the opposite is the case. With the large gap, the relative lengths of the flux paths into the slots are shorter, compared with the direct iron-to-iron paths, than with a short gap, other conditions being equal, and consequently the fringing into the slots will be greater, Fig. 13. An obvious means for lessening this flux is to sink the armature conductors a considerable distance below the gap surface, and this is common practice in modern machines. Fairly large air-gaps are necessary on large turbogenerators; so that, without special precautions, such as sunken coils, well laminated conductors, etc., the losses from the gap flux would be much larger than in usual types of machines.

The lamination of the conductors of turbogenerators has been quite a problem. Various methods of subdivision and of insulation of the individual strands, have been tried. Enamels and varnishes of various sorts, cotton coverings, and taping with mica paper have been used. Due to the high temperatures inside the coils themselves, which almost invariably occur in large turbogenerators, the use of mica on the individual strands appears to be the only really safe and satisfactory method, just as mica in the outside wrapper represents the best practice. In order to subdivide the large conductors more completely, it is a not infrequent practice to subdivide the armature circuits into two or more parallels, by which means, certain transpositions of the conductors and their elementary strands can be obtained, with consequent reduction in the eddy current losses.

VOLUME OF COOLING AIR AND WINDAGE LOSSES

Reference has been made to the difficulties in obtaining the requisite cooling air. It is the enormous volume of air required that is back of much of the difficulty. As a rough approximation, assume the total generator losses, including windage, as four percent of the rated capacity; or the loss in kilowatts is equal to 0.04 × kw capacity. Also accepting the well-known relation that one kv loss will raise the temperature of 100 cubic feet of air 18 degrees C. in one minute, then four cubic feet of air per minute is required per kw capacity of the machine for 18 degrees C. rise of the air, or three cubic feet per kw for 24 degrees C. rise. This is only a crude statement of the problem, but it indicates that for a 30 000 kw or kv-a. generator, a total of about 90 000 cubic feet of air per minute is required. This volume, in practice, will actually lie between 75 000 and 100 000 cubic feet, depending upon the total losses, (including windage itself), and upon the air temperature rise allowed. In any case it is very large and the real problem is to obtain sufficient cross-section of air inlet without unduly high air velocities. Assuming a maximum velocity of 9000 feet per minute, the minimum cross-section of the air path must be about nine square feet, or equivalent to an opening three feet square,—an apparently impossible figure from casual observation of the air-gap and other air channels through the machine. But even 9000 ft. air velocity is very high and means quite considerable pressures for forcing the air through the machine, with consequent high windage losses.

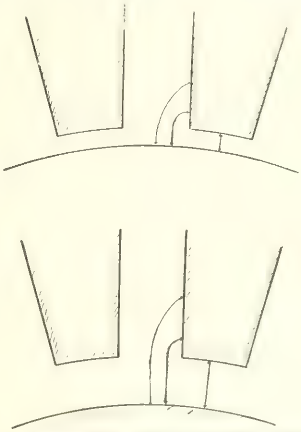


FIG. 13—RELATIVE LENGTHS OF FLUX PATHS
With large and short air-gaps

Whether the core loss proper be taken care of by axial or radial duct ventilation, a large volume of air is required to take up the total gap losses and this alone means comparatively large windage losses. With any reasonably well-designed method of ventilation, it is possible to get the requisite air through the machine with the desired cooling effect, provided suitable pressure is obtainable. However, the higher the pressure with a given volume of cooling air, the higher will be the losses, other conditions being approximately the same. In consequence, there is a limit to the permissible pressure which can be used.

The efficiency of the fan which provides the pressure, is an element of the problem, but when one considers that more than one-half of the total windage loss is inside the machine and independent of the fan itself, it is evident that the fan efficiency is not a dominating feature, although it is important.

The problem of artificial cooling is more complex in the turbogenerator than in any other type of electric machine, and it may be said that more engineering effort has been, and is being spent on this than any other problem in this class of apparatus. Each step upward, in capacity or in speed opens the problems anew, for in each of the preceding advances the designers have usually strained to the utmost to meet the necessities of the case.

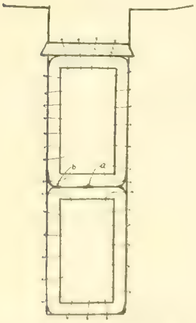


FIG. 14—APPLICATION OF TEMPERATURE INDICATOR

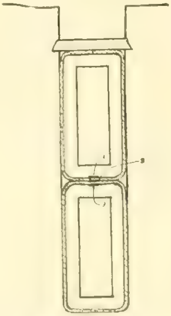


FIG. 15—INDICATORS IN SEPARATE FIBRE CELLS

To the uninitiated, the volume and the weight of air required to cool the modern turbogenerator is always a matter of surprise. Without the figures before one, it is almost unbelievable that a modern large capacity turbogenerator *puts through itself practically its own weight in cooling air in forty to sixty minutes.* Obviously, unless this air is clean, the total amount of dirt and other foreign substance which pass through the machine, in even a few days' time, will be enormous, and a very small percentage of this, deposited inside the machine, may soon seriously clog the ventilating passages and thus interfere with the operation of the machine. This indicates why air washers and other devices, for preventing or lessening the admission of dirt, have become almost a necessity in such machinery.

TEMPERATURE DETERMINATION

There are two special problems in the temperature determination of large turbogenerators, namely, location of the hottest part, and measurement of the temperature by such method as will give a fairly close approximation to the actual results. The former problem is easier than the latter, as it simply involves a multiplicity of measurements on a given type or construction of machine, until a reasonably accurate location is determined, which may be applied on other machines of the same type.

The second problem is difficult. If one could apply temperature indicators directly to the copper itself, of course the actual highest copper temperatures could be obtained directly. But this is not practicable except under what may be called laboratory conditions. The requisite continuity of the insulation over the copper makes difficult any measurement directly on the copper itself. Therefore, certain approximate methods have been adopted, which have proven fairly satisfactory, but which must be used with judgment. The results are dependent upon the method of application, the type of ventilation used and other considerations. The method now used most extensively depends upon the placing of the temperature indicator between upper and lower coils in the same slot, and, therefore, is predicated upon the two-coils-per-slot arrangement, which is the common practice in this country. The theory of the method is based upon the principles of heat flow from the two coils.

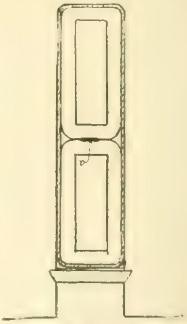


FIG. 16—TEMPERATURE INDICATORS IN A SINGLE HARD FIBRE CELL

Thus in Fig. 14, arrows indicate the general paths of heat flow from the two coils. Assuming the copper temperatures of the two coils as equal, and the width of the coils to be considerable, then at the mid-point *a* between the upper and lower coils the temperature should be practically midway between the upper and lower copper temperatures, and an indicator at this point should show about the same temperature as the copper. This is not exactly true, for there is some heat flow along the insulation from the mid-point *a*, so that this point will probably be slightly lower than the true mid-temperature between the coils. A point *b*, between the coils but at the corner next the iron should have a temperature very nearly equal to that of the iron itself. Its temperature should thus be very much lower than that of *a*. Between *b* and *a* there should be intermediate temperatures, depending upon the distance from the center point *a*. It should be obvious, therefore, that a temperature indicator covering practically the full width of the slot, will show some average value between *b* and *a*. Therefore, for greatest accuracy the indicator should be as narrow as possible, and be placed at *a*.

Another consideration involves the method of applying the usual slot cells. Turbo-armature coils are commonly "pushed home" in hard fibre cells placed next to the iron. This serves as a protection for the insulation proper, in putting the coil in place, and also makes a tighter fit in the slot. There are two general methods of applying these cells. In one, the cell is placed over the lower coil, and then folded over its upper side, either during manufacture of the coil, or before the upper coil, with a corresponding cell, is put in place, Fig. 15. In the second arrangement, the two coils are set in a single cell, which is then folded over the top one, as in Fig. 16.

With the two-cell arrangement, there are three places to put the temperature indicator,—(1) below the upper coil and inside the cell,—(2) above the lower coil, but inside the cell, and (3) between the upper and lower cells. In position (1) the indicator will tend to show more nearly the temperature of the upper coil, while in (2) it tends to indicate more nearly the lower coil temperature. When placed in position (3) it should be intermediate between (1) and (2), provided this position is thoroughly shielded from external influences.

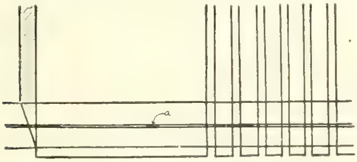


FIG. 17—APPLICATION OF TEMPERATURE INDICATORS TO STATORS HAVING BOTH AXIAL AND RADIAL VENTILATION

In the single cell arrangement, there is but one location for the indicator between the coils unless a separating strip of appreciable thickness is placed between the upper and lower coils. Obviously, with this single cell, the indicator is well shielded from external influences, such as the ventilating air, that might come in contact with the measuring device at the radial air ducts.

Considering next, the application of such indicators to the axial and the radial types of stators, it will be noted that, if the indicator be located as indicated in Fig. 17, at point *a*, there is no chance for the ventilating air to come in contact with the indicator, regardless of whether the single or double slot coil arrangement is used.

However, if placed in the central radially ventilated section or zone, the conditions may be quite different, but not necessarily so, depending upon the construction and application of the indicator, etc. Here the coils are partly embedded in iron and lie partly in the radial ventilating ducts. The indicated result will depend upon whether the measurement is taken at *a* or *b*, for instance, Fig. 18. This difference, however, may be quite small if the detector is thoroughly shielded from the ventilating air in the duct. It may be suggested that, as the coils are ventilated in the duct, the indicator should be ventilated also. But we are not after the temperature of the outside or exposed surface of the insulation, but are attempting to approximate the internal copper temperatures. *The indicator should thus be as well shielded, if possible, as the copper inside the coils.* The single slot cell arrangement thus appears to be more accurate than the double cell, with the indicator outside the cells, when the indicator is placed close to, or bridges one or more ventilating ducts. Thus, in the axially ventilated type of stator, the ventilating device should not be used in the central radially-ventilated zone, unless unusual precautions are taken to avoid the discrepancies which are liable to result.

Thus a certain amount of judgment and skill is necessary to obtain the closest possible approach to the true copper temperatures. Furthermore, the problem is complicated by the fact that the upper coil in the slot is liable to be hotter than the lower one, due to higher eddies in the upper copper. At best, therefore, the method as a whole is only an approximation, but it gives so much closer to the correct result than any of the measuring methods in use a few years ago, that it marks a decided step in advance in generator temperature measurements.

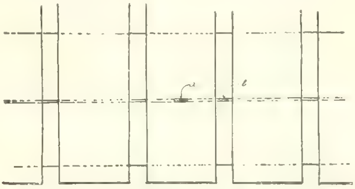


FIG. 18—MEASURING TEMPERATURES IN CENTRAL RADIALLY VENTILATED ZONES

As far as temperatures in the stator are concerned, they are not of serious importance except as they have an influence on the copper and insulation temperatures, and even the copper temperature in itself is of importance only as it affects the insulation. In fact, it is solely the insulation durability which we are after, in the last analysis. The improvements, and refinements in design, betterments in the grade of insulation, innovations in ventilation, etc. all are directed to the one end, not the temperature itself, but the factor of safety of the insulating materials.

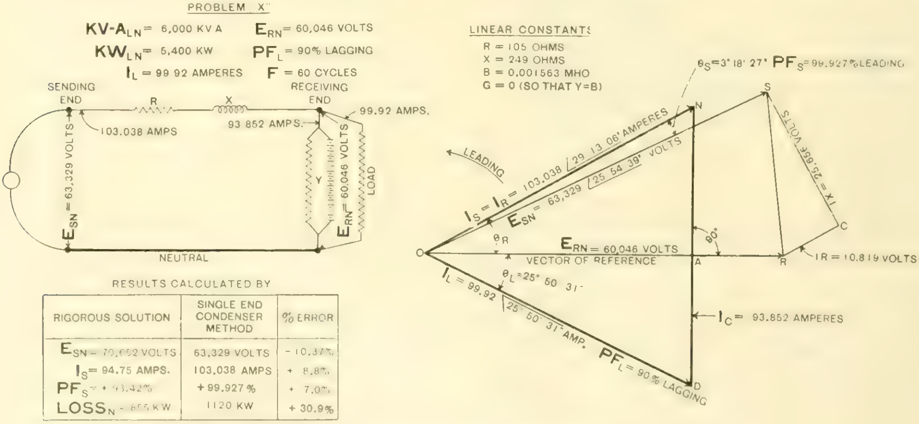
Electrical Characteristics of Transmission Circuits-XII

Comparison of Various Methods

Wm. Nesbit

The "localized capacitance" or "localized admittance" methods are discussed below for the two following reasons. A discussion of them is of academic interest and a tabulation of the magnitude of the errors in the results as obtained by these approximate methods when applied to circuits of different lengths and frequencies should be helpful. These methods may be carried out either graphically or mathematically, but since they are only approximate the simpler graphical solution should suffice. Their principle virtue is the fact that they simplify the determination of performance, but this is obtained at the expense of accuracy. The more accurate of these methods is somewhat tedious to carry out. The graphical solution previously described in connection with the Wilkinson charts will be generally more accurate and shorter than these localized capacitance methods.

THE LOCALIZED CAPACITANCE methods are:—the single end condenser method; the middle condenser or *T* middle condenser or *T* method; the split condenser or nominal π method and Dr. Steinmetz three condenser method. These four lumped capacitance methods assume the total capacitance of the circuit as being divided up and "lumped" in the form of condensers shunted across the circuit at one or more points.



RESULTS CALCULATED BY

RIGOROUS SOLUTION	SINGLE END CONDENSER METHOD	% ERROR
E_{SN} = 70,652 VOLTS	63,329 VOLTS	− 10.37%
I_S = 94.75 AMPS.	103.038 AMPS	+ 8.8%
PF_S = + 93.42%	+ 99.927 %	+ 7.0%
$LOSS_N$ = 855 KW	1120 KW	+ 30.9%

FIG. 54—SINGLE END CONDENSER METHOD
Problem X.

The single condenser method assumes the total capacitance as being lumped or shunted across the circuit at the receiving-end. On this assumption the total charging current for the circuit would flow over the entire circuit. Actually the charging current is distributed along the circuit so that the entire charging current does not flow over the entire circuit. Obviously the assumption of the total capacitance being lumped at the receiving-end will therefore give over compensation for the effect of the charging current upon the voltage regulation of the circuit. This method of solution yields a voltage too low at the sending end by nearly the same amount that the straight impedance method gives it too high. By averaging the values, as obtained by the impedance and single end condenser methods, usually an approximation to the true value may be obtained.

The middle condenser or *T* method assumes that the total capacitance may be shunted across the circuit at the middle point. On this assumption the total charging current will flow over one half the length of the circuit. This method is therefore more nearly accurate than the single-condenser method.

The split condenser π method assumes one half the capacitance being shunted across the circuit at each end. In this case one-half of the charging current flows over the entire circuit. This assumed distribution of the charging current also more nearly represents the actual distribution than the single-condenser method.

Dr. Steinmetz has proposed a method assuming three condensers shunted across the circuit. One in the middle, of two-thirds, and one at each end, each of one sixth the total capacitance of the circuit. This method is equivalent to assuming that the electrical quantities are distributed along the circuit in a way representing an arc of a parabola. This method assumes one-sixth the charging current flowing over one half the entire circuit and five sixth the charging current flowing over the other half of the circuit. This method gives quite accurate results unless the circuit is very long and the frequency high.

Figs. 54-57 show leaky condensers placed at different points of the circuits, that is they indicate that there is a leak G, as well as a susceptance B. For simplicity pure condensers have been assumed in the accompanying calculations; that is we have assumed $G=0$. This is the usual assumption in such cases, for the reason that G is usually very small, and localized capacitance methods are approximations at best. In the equivalent π solution previously given, we have indicated the treatment when the condensers have a leak. In such case, however, the equivalent π method produces exact results, and the nature of such solution may demand a condenser having a material leak.

AUXILIARY CONSTANTS

Mr. T. A. Wilkinson and Dr. Kennelly have worked out the algebraic expressions for the auxiliary constants corresponding to these four circuits of localized capacitance. These are given in Table Q. It may be interesting to observe to what extent each of the four localized capacitance methods takes account of the three linear line constants R, X and B. The rigorous or exact expression for the auxiliary constants is given under Table Q for comparison with the values corresponding to the localized condenser methods. The numerals under the algebraic expressions correspond to problem X; that is, to a certain 60 cycle circuit, 300 miles long. They are given to illustrate for a long circuit, the account taken of the fundamental constants for each of the five methods listed. These numerals may be compared with the rigorous or exact values as given under the rigorous expressions at the bottom of the table.

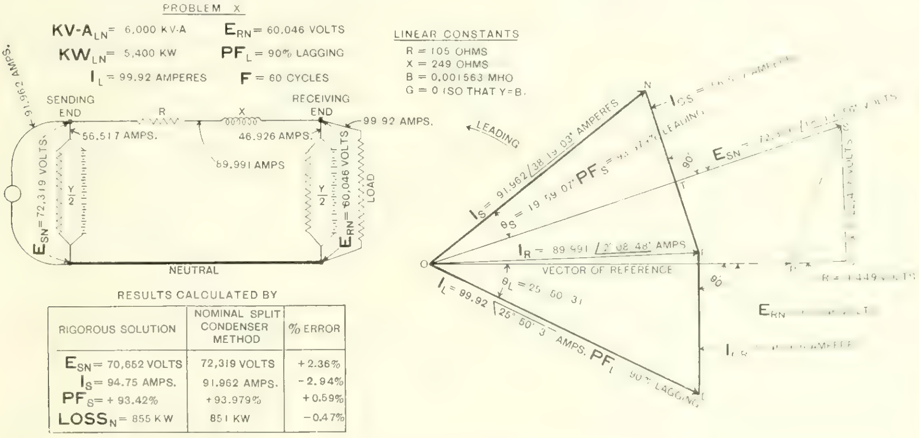
SINGLE END CONDENSER METHOD

This method assumes that the total capacitance of the circuit may be concentrated across the circuit at the receiving-end. In such case the entire charging current would flow over the total length of the circuit.

Solution by Impedance Method—The diagrams of connections and corresponding graphical vector solution for problem X by the single end condenser method is indicated by Fig. 54. The current DN consumed by the condenser (zero leakage assumed) leads the receiving-end voltage OR by 90 degrees and is,—

I [illegible] 0.001563 [illegible] 60046 [illegible]

The load current of 99.92 amperes, lagging 25° 50′ 30″ (90% power-factor) has a component OA of *99.92 × 0.90 = 89.928 amperes* in phase with the receiving-end voltage and a component AD of *99.92 × 0.4359 = 43.555* amperes in lagging quadrature with the receiving-end voltage. This lagging component is therefore in opposite direction to the charging current, the effect of which is to neutralize an equivalent amount of charging current. The remaining current AN in leading quadrature with the receiving-end voltage is *93.852 — 43.555 = 50.297* amperes. The current ON in the conductor is therefore:—



RESULTS CALCULATED BY

RIGOROUS SOLUTION	NOMINAL SPLIT CONDENSER METHOD	% ERROR
E$_{SN}$ = 70,652 VOLTS	72,319 VOLTS	+ 2.36%
I$_S$ = 94.75 AMPS.	91.962 AMPS.	- 2.94%
PF$_S$ = + 93.42%	+ 93.979%	+ 0.59%
LOSS$_N$ = 855 KW	851 KW	- 0.47%

FIG. 55—NOMINAL π OR SPLIT CONDENSER METHOD
Problem X.

I [illegible] 50.297 [illegible] 89.928 [illegible]
$= 103.038$ *amperes.*

The current at the sending-end leads the voltage at the receiving-end by the angle θ_R whose tangent is,—

[illegible] 13′ 06″

The voltage consumed by the resistance, and the reactance of each conductor is,—

IR [illegible] (resistance drop)
IX [illegible] (reactance drop)

The receiving-end conditions are thus,—

I [illegible] 103.038 [illegible]
$\theta_R = 29° 13' 06''$
$\cos \theta_R = 0.8772$
$\sin \theta_R$ [illegible]

and from (40)*,—

---

*p. 76, Feb. 1920.

$$E_S = \sqrt{(60036 \times 0.727 + 10819)^2 + (60036 \times 0.681 - 25656)^2}$$

$$= 63{,}380 \,\underline{/3^\circ\ 18'\ 27''} \text{ volts to vector } ON$$

$$= 63{,}380 \,\underline{/25^\circ\ 51'\ 39''} \text{ volts to vector of reference}$$

$$P.F. = \cos \underline{/3^\circ\ 18'\ 27''} = 99.827 \text{ percent leading.}$$

$$K.V.A. = 103.038 \times 63.380 = 6{,}531 \text{ kv-a.}$$

$$K.W. = 6{,}531 \times 0.99827 = 6{,}520 \text{ kw.}$$

$$Loss = 6{,}520 - 5{,}400 = 1120 \text{ kw.}$$

Solution by Complex Quantities—From Table *Q* the auxiliary constants corresponding to the single end condenser method are found as follows:—

$a_1 = 1 - XB = 0.610813$
$a_2 = RB = 0.164115$
$b_1 = R = 105$ *ohms*
$b_2 = X = 249$ *ohms.*
$c_1 = O$
$c_2 = B = 0.001563$ *mho*

The voltage at the sending end is determined as follows:—

$$
\begin{aligned}
I_R\,(\cos\theta_1 - j\,\sin\theta_1) &= 89.928 - j\,43.555\\
\times\,(b_1 + j\,b_2) &= 20{,}286 + j\,17{,}820\\
+\,E_R\,(a_1 + j\,a_2) &= 36{,}677 + j\,9{,}851\\
\hline
E_S &= 56{,}963 + j\,27{,}673\\
&= 63{,}380 \,\underline{/25^\circ\ 51'\ 39''} \text{ volts.}
\end{aligned}
$$

which checks exactly with the results as obtained previously by the impedance method.

The current at the sending end may be determined as follows:

$$
\begin{aligned}
I_R\,(\cos\theta_1 - j\,\sin\theta_1) &= 89.928 - j\,43.555\\
+\,E_R\,(c_1 + j\,c_2) &= 0 + j\,93.852\\
\hline
I_S &= 89.928 + j\,50.297\\
&= 103.038 \,\underline{/29^\circ\ 13'\ 06''} \text{ amperes}
\end{aligned}
$$

which also checks exactly with the result as previously determined by the impedance method.

It should be noted here that in determining the sending end current, the auxiliary constant $(a_1 + j\,a_2)$ did not enter into the calculation as it does in the rigorous solution; this is owing to the inherent dissymmetry of the single-end condenser. This is the only case in which the capacitance is applied dissymmetrically, consequently the current entering the line at the sending end is completely determined by the load current at the receiving-end and the vector addition thereto of the current supplied at that end to the condenser under receiving-end voltage. For determining the sending-end voltage $A'_V = 1 + YZ$ and $B'_V = Z$; but for determining the sending-end current $A'_I = 1$ and $C'_I = Y$. If the condenser were applied symmetrically A'_V *and* A'_I would be identical.

SPLIT CONDENSER OR NOMINAL π SOLUTION

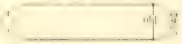
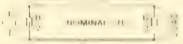
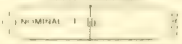
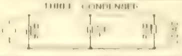
This method assumes that the total capacitance of the circuit may be concentrated at the two ends, one-half being placed across the circuit at either end. In this case one-half the charging current flows over the entire circuit. The total resistance and the total reactance of one conductor is placed between the two terminal condensers.

With this assumption the current consumed by the condenser across the receiving-end of the circuit is added vectorially to the load current and the power-factor of the combined currents calculated. With these new load conditions determined the conditions at the sending-end are calculated by the impedance method. This is the only calculation required when employing the nominal π method for determining the sending-end voltage. The voltage at the sending-end is therefore more readily calculated by this method than by the *T* method which requires the calculation of the two separate halves of the circuit. If, however, the current, power-factor and kw input are required, a second calculation must be made to determine them. In such cases the current consumed by the condenser at the sending-end must be added vectorially to that of the line conductors.

Solution by Impedance Method—The diagrams of connections and corresponding graphical vector solutions for problem *X* by the nominal π method is indicated in Fig. 55. The charging current consumed by the condenser (zero leakage assumed) at the receiving-

TABLE Q—AUXILIARY CONSTANTS

CORRESPONDING TO CIRCUITS OF LOCALIZED CAPACITANCE

METHOD	a_1	a_2	b_1	b_2	c_1	c_2	EQUIVALENT CONVERGENT SERIES FORM OF EXPRESSION ★
IMPEDANCE	1	0	R $=105$	X $=+j\,249$	0	0	$A' = 1 \quad B' = Z \quad C' = 0$
SINGLE END CONDENSER 	$1-XB$ $=0.610813$	RB $=+j\,0.164115$	R $=105$	X $=+j\,249$	0	B $=+j\,0.001563$	$A' = 1+YZ \quad B' = Z \quad C' = Y$
DOUBLE END CONDENSER 	$1-\frac{XB}{2}$ $=0.8054065$	$\frac{RB}{2}$ $=+j\,0.0820575$	R $=105$	X $=+j\,249$	$-\frac{B^2R}{4}$ $=-0.000\,0641$	$B-\frac{B^2X}{4}$ $=+j\,0.001411$	$A' = (1+\frac{YZ}{2}) \quad B' = Z \quad C' = Y(1+\frac{YZ}{4})$
MIDDLE CONDENSER 	$1-\frac{XB}{2}$ $=0.8054065$	$\frac{RB}{2}$ $=+j\,0.0820575$	$R-\frac{RXB}{2}$ $=84.5677$	$X-\frac{B}{4}(X^2-R^2)$ $=+j\,229.081$	0	B $=+j\,0.001563$	$A' = (1+\frac{YZ}{2}) \quad B' = Z(1+\frac{YZ}{4})$ $C' = Y$
THREE CONDENSER 	$1-\frac{XB}{2}+\frac{B^2}{36}(X^2-R^2)$ $=0.8088661$	$\frac{RB}{2}-\frac{RXB^2}{18}$ $=+j\,0.0785090$	$R-\frac{RXB}{3}$ $=91.3785$	$X-\frac{B}{6}(X^2-R^2)$ $=+j\,235.721$	$-\frac{5RB^2}{36}+\frac{RXB^3}{108}$ $=-0.0000347$	$B-\frac{5XB^2}{36}+\frac{B^3}{216}(X^2-R^2)$ $=+j\,0.0014794$	$A' = (1+\frac{YZ}{2}+\frac{Y^2Z^2}{36}) \quad B' = Z(1+\frac{YZ}{6})$ $C' = Y(1+\frac{5YZ}{36}+\frac{Y^2Z^2}{216})$

★ THE EXACT CORRESPONDING EXPRESSIONS FOR THE AUXILIARY CONSTANTS ARE GIVEN BELOW. THE NUMERICAL FIGURES CORRESPOND TO PROBLEM X

$$A = (1 + \frac{YZ}{2} + \frac{Y^2Z^2}{24} + \frac{Y^3Z^3}{720} + \frac{Y^4Z^4}{40\,320} + \ldots) = \cosh\theta = 0.81058 + j\,0.07681$$

$$B = Z(1 + \frac{YZ}{6} + \frac{Y^2Z^2}{120} + \frac{Y^3Z^3}{5\,040} + \frac{Y^4Z^4}{362\,880} + \ldots) = Z_0 \sinh\theta = 91.7480 + j\,236.866$$

$$C = Y(1 + \frac{YZ}{6} + \frac{Y^2Z^2}{120} + \frac{Y^3Z^3}{5\,040} + \frac{Y^4Z^4}{362\,880} + \ldots) = Y_0 \sinh\theta = -0.000\,0411 + j\,0.0014814$$

end of the circuit leads the receiving-end voltage by 90 degrees and is,—

$$I_{cr} = \frac{0.001563}{2} \times 60\,046 = 46.926 \textit{ amperes.}$$

The current I_r in each conductor is the vector sum of the load and condenser currents and may be determined as follows:—

$$I_r = \sqrt{(99.92 \times 0.90)^2 + (I_{cr} + 99.92 \times -0.4359)^2}$$
$$= 89.991 \;\underline{/2°\ 08'\ 48''} \textit{ amperes}$$
$$PF_r = \text{Cos } 2°\ 08'\ 48'' = 99.93 \textit{ percent leading.}$$

The voltage consumed by the resistance, and the reactance of each conductor is,—

$$IR = 89.991 \times 105 = 9449 \textit{ volts (resistance drop)}$$
$$IX = 89.991 \times 249 = 22\,408 \textit{ volts (reactance drop)}$$

and from (40),—

$$E_{sn} = \sqrt{(60\,046 \times 0.9993 + 9449)^2 + (60\,046 \times 0.037458 + 22\,408)^2}$$
$$= 72\,319 \;\underline{/16°\ 11'\ 08''} \textit{ volts to current vector } OP.$$
$$= 72\,319 \;\underline{/18°\ 19'\ 56''} \textit{ volts to vector of reference } OR.$$

The charging current consumed by the condenser at the sending-end (zero leakage assumed) leads the voltage at the sending-end by 90° and is,—

$$I_{cs} = \frac{0.001563}{2} \times 72\,319 = 56.517 \textit{ amperes.}$$

The current at the sending-end is the vector sum of the current in the conductor and the current consumed by the condenser at the sending-end. It may be calculated as follows:—

$$OT = 89.991 \;(\text{Cos } 16°\ 11'\ 08'') = 86.421 \textit{ amperes.}$$
$$TP = 89.991 \;(\text{Sin } 16°\ 11'\ 08'') = 25.085 \textit{ amperes}$$
$$TN = 56.517 - 25.085 = 31.432 \textit{ amperes.}$$

therefore,—

$$I_s = \sqrt{86.421^2 + 31.432^2}$$
$$= 91.962 \;\underline{/19°\ 59'\ 07''} \textit{ amperes to vector } OS.$$
$$= 91.962 \;\underline{/38°\ 19'\ 03''} \textit{ to vector of reference } OR.$$
$$PF_s = \text{Cos } 19°\ 59'\ 07'' = 93.979 \textit{ percent leading.}$$
$$KV\text{-}A_{sn} = 91.962 \times 72.319 = 6651 \textit{ kv-a.}$$
$$KW_{sn} = 6651 \times 0.93979 = 6251 \textit{ kw.}$$
$$Loss_n = 6251 - 5400 = 851 \textit{ kw.}$$
$$Eff = \frac{5400 \times 100}{6251} = 86.37 \textit{ percent.}$$

Solution by Complex Quantities—From Table Q the auxiliary constants corresponding to the nominal π method of solution are found as follows:—

$$a_1 = 1 - \frac{XB}{2} = 0.8054065.$$
$$a_2 = \frac{RB}{2} = 0.0820575.$$
$$b_1 = R = 105 \textit{ ohms}$$
$$b_2 = X = +j\,249 \textit{ ohms}$$
$$c_1 = -\frac{RB^2}{4} = -0.0000641 \textit{ mho}$$
$$c_2 = B\left(1 - \frac{XB}{4}\right) = 0.001411 \textit{ mho}$$

The voltage at the sending-end is determined as follows:

$$I_L (\text{Cos } \theta_L - j \text{ Sin } \theta_L) = 89.928 - j43.555.$$
$$\times (b_1 + jb_2) = 20\,286 + j17\,819 \textit{ volts.}$$
$$+ E_{rn} (a_1 + ja_2) = 48\,361 + j\,4927 \textit{ volts.}$$
$$E_{sn} = 68\,647 + j22\,746.$$
$$= 72\,319 \;\underline{/18°\ 19'\ 56''} \textit{ volts}$$

The current at the sending-end may be determined as follows:—

$$I_L (\text{Cos } \theta_L - j \text{ Sin } \theta_L) = 89.928 - j43.555$$
$$\times (a_1 + ja_2) = +76.003 - j27.700 \textit{ amperes}$$
$$+ E_{rn} (c_1 + jc_2) = -3.849 + j84.718 \textit{ amperes}$$
$$I_s = 72.154 + j57.018.$$
$$= 91.962 \;\underline{/38°\ 19'\ 03''} \textit{ amperes.}$$

The above results check exactly with those previously obtained by impedance calculations. This agreement indicates that the nominal π solution may, if desired, be used with complex quantities, assuming values for the auxiliary constants as indicated in Table Q.

Convergent Series Expression—Table Q indicates that the nominal π solution is equivalent to using the following values for the auxiliary constants in the convergent series form of solution,—

$$A' = \left(1 + \frac{YZ}{2}\right),\quad B' = Z,\quad C' = Y\left(1 + \frac{YZ}{4}\right)$$

We will now show that the above expressions yield the same values for the auxiliary constants as given in Table Q. From chart *XI** the following values corresponding to problem *X* are taken.

$$ZY = -0.389187 + j\,0.164115$$

therefore,

$$A' = 1.0000000$$
$$-0.1945935 + j\,0.0820575$$
$$A' = 0.8054065 + j\,0.0820575$$
$$B' = 105 + j\,249$$
$$C' = 1.000000$$
$$-0.0972967 + j\,0.0410287$$
$$= Y\,(0.9027033 + j\,0.0410287)$$
$$C' = -0.0000641 + j\,0.001411$$

Thus the values for the auxiliary constants as determined by the above incomplete convergent series expression check with those as determined above from the equations in Table Q.

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*p. 151, April 1920.

(*To be continued*)

A Record of Large Turbogenerator Armature Breakdowns

F. D. Newbury

THE FOLLOWING statement is a complete record of armature breakdowns that have occurred in Westinghouse turbogenerators of 15 000 kv-a. or larger, polyphase rating.* The record covers every Westinghouse turbogenerator of this size that had been placed in operation up to January 1920. These generators, without exception, are mica insulated, with mica insulation between strands and between conductors, as well as between coil and core.

The first Westinghouse generators larger than 10 000 kv-a. were placed in operation in 1913. These were generators, roughly 20 000 kv-a. in size, two pole in the case of 25 cycles and four pole in the case of 60 cycles. The design of such large two and four pole units in 1911 and 1912 was highly experimental, and while these units met the standard temperature rise guarantee of 50 degrees C by thermometer, it has since been found that the strands nearest the air-gap at the middle of the core have had at least 200 degrees C rise in some cases. Experience has shown designers how to avoid these high local temperatures to a considerable degree (mainly by reduction of eddy curent losses) and this is mentioned here only to bring out the significance of the record of trouble due to heating. It is also important to note the inclusive and representative nature of the record. It covers all generators built of a given size and type and it is therefore safe to draw general conclusions that will be applicable to all generators of the same class.

During these seven years experience there have been 22 cases of major armature trouble involving 12 different installations or designs and 16 individual units. By major armature trouble, is meant trouble serious enough to result in the failure of one or more armature coils.

The classification of armature failures as to cause is in some cases a difficult matter. The events leading up to the trouble may be unknown and the evidence is very often burnt up. It has been thought best, therefore, to separate these cases into three classes as follows:—

1—Where the manufacturer has accepted responsibility.

2—Where the operating company has accepted responsibility.

3—Where the cause is unknown or in dispute.

1—*Eight cases* were chargeable to design workmanship or other causes for which the manufacturer accepted responsibility.

  a—*Five cases* (of these eight) were caused by defects in manufacture that developed very shortly after installation.

  b—*Three cases* (of these eight) concerned details of design that led to failure after four or five years operation. Two of these cases (in one design) involved high local temperatures caused by eddy currents in the top strands of the coil.

2—*Eleven cases* were chargeable to operating hazards for which the operating company accepted the responsibility.

  a—*Four cases* (of these 11) were caused by fires originating outside of the armature winding. In three of these cases the fire started in the cables just outside of the generator; in the fourth case the fire started in a series transformer accidentally open circuited.

  b—*Four cases* (of these 11) occured in one installation and were caused by abnormal voltage surges that caused the outside surfaces of the insulation to catch fire. In addition to these four cases that resulted in coil failures, as many more fires started that were put out before such damage was done. This trouble disappeared after the generator neutral was grounded.

  c—*One case* (of these 11) was caused by ice or water (it occurred on Feb. 28) carried into the generator from the air washer.

  d—*Two cases* (of these 11) were caused by intentional operation under conditions that were known to be unsafe. One case involved unsafe overloads and the other case involved continued operation after it was known that the armature needed minor repairs.

3—*Three cases* inolved unknown causes or the cause was in dispute.

  In two of these cases the operating company believed armature coil heating to be responsible.

This classification of armature breakdowns shows that out of 19 cases, where causes were agreed to, 11 cases were caused by operating hazards for which the generator can in no way be held accountable.

If all the cases in which armature heating was involved (even by suspicion) are grouped, there are only five cases out of 22 breakdowns. Two cases (involving one of the first designs) were caused by design proportions; in two others temperature was not the primary cause of breakdown, but the operating companies believed it to be a contributory cause; and in the fifth case enforced overloading was the primary cause.

The writers opinion, based on a careful study of operating experience and based on a detailed knowledge of internal temperatures and coil and insulation design, is that breakdowns caused by armature heating are in reality due to abnormal local temperatures that have values of the order of several hundred degrees; and that temperatures of 100 or 150 degrees ordinarily discussed in connection with guarantees have very little to do with the problem. This statement, of course, applies only to windings completely insulated with mica within the slots.

This record of breakdowns brings to the surface another fact that is interesting and important, and that is reassuring to the companies operating high voltage units. There are twice as many generators wound for 11 000 volts, or higher voltage, as there are generators wound for lower voltages. But these twenty-two cases of armatures breakdown are equally divided between these two voltage classes. This means that the percentage of armature breakdowns in the high-voltage generators under discussion is only one-half that of the lower voltage generators. This record would be very different with treated cloth insulation (in large high-voltage generators), or with partially closed armature slots.

This record does not prove that high voltage generators are necessarily safer or less subject to breakdown, except in so far as breakdowns may be caused by voltage surges that are independent of generator voltage. Obviously a 10 000 volt surge would be dangerous in a 2400 volt generator but would be harmless in a 13 000 volt winding. The record does prove that 11 000 and 13 000 volt windings are just as reliable as low-voltage windings and, further, that breakdowns are generally caused by trouble unrelated to line voltage.

The facts brought out by this record may be summarized as follows:—

1—The majority of armature breakdowns are caused by operating hazards originating outside the generator.

2—Armature heating in armatures completely insulated with mica is a minor cause of breakdown.

3—High voltage generatores, with mica insulation and open armature slots, are as reliable and probably are more so than large low-voltage generators.

*This article is based on a discussion of a paper by Phillip Torchio, presented at the A. I. E. E. Convention, June, 1920.

Switchboard Meter Connections for Alternating-Current Circuits—VIII

Measuring Reactive Volt-Amperes in Three-Phase Three-Wire Circuits

J. C. Group

A POLYPHASE wattmeter with special calibration may be used for measuring the reactive volt-amperes in a three-phase, three-wire circuit when connected as in Fig. 86. The connections are the same as in Fig. 76, but the voltage transformers have standard secondary windings with a middle tap. The voltage and current relations are as shown in the vector diagram in Fig. 87, which is for the condition of a balanced load at any power factor where the current lags by an angle ϕ. The voltage E_R impressed on the voltage coil of the right hand element of the wattmeter is $E_{2\,3} + 1/2\, E_{1\,2}$ (vectorially) and being 30 degrees ahead of $E_{2\,3}$ is equal to $E_{2\,3} \cos 30°$ or, omitting the sub-figures since $E_{2\,3}$ is the line voltage, $= 0.866\, E$. Likewise the voltage E_L impressed on the voltage coil of the left hand element of the wattmeter is $0.866\, E_{1\,2}$ or $0.866\, E$ when expressed in terms of the line voltage E. For the angle of lag ϕ the line currents are $30° + \phi$ behind the line voltages. I_1 is $60° - \phi$ ahead of E_R and the measurement in the right hand element is $E_R\, I_1 \cos (60° - \phi)$ or, expressing E_R in terms of the line voltage E and omitting the sub-figure from I_1 since it is the line current, $W_R = 0.866\, E\, I \cos (60° - \phi) = 0.866\, E\, I\, (1/2 \cos \phi + 0.866 \sin \phi) = 1/4\; 1.73\, E\, I\, (\cos \phi + 1.73 \sin \phi)$. I_3 is $120° - \phi$ ahead of E_L and the measurement in the left hand element is $E_L\, I_3 \cos (120° - \phi)$ or, expressing E_L in terms of the line voltage E and omitting the sub-figures from I_3 since it is the line current, $W_L = 0.866 \cos (120° - \phi) = 1/4\; 1.73\, E\, I\, (1.73 \sin \phi - \cos \phi)$. The algebraic sum of the measurements in the two elements $W = 3/2\, E\, I \sin \phi$. Multiplying this result by $2/3\; 1.73$ (approximately 115%), which should be taken care of by the special calibration of the meter, gives $1.73\, E\, I$ which is correct for the reactive volt-amperes in the three-phase, three-wire circuit. This method is correct for balanced or unbalanced loads at any power-factor, whether the current lags or leads, the same as for the connection in Fig. 76.

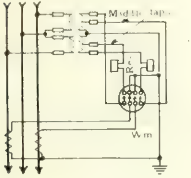


FIG. 86 MEASURING REACTIVE VOLT-AMPERES
Using standard voltage transformers.

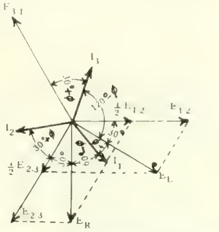


FIG 87 BALANCED LOAD AT ANY POWER-FACTOR
With connections shown in Fig. 86.

A polyphase wattmeter with special calibration, or with standard calibration and used with a multiplier of 0.866 will also correctly measure the reactive volt-amperes of a *balanced load* on a three-phase three-wire circuit when connected as shown in Fig. 88. The voltage transformers are standard, and the connections differ from those common for measuring the true power in that the voltage which is commonly connected to the voltage coil in the right hand element is connected to the voltage coil in the left hand element, and the voltage which is commonly connected to the voltage coil in the left hand element is connected to the voltage coil in the right hand element reversed.

The vector relations of voltages and currents for a balance load at unity power-factor may be explained from the vector diagram in Fig. 89. $E_{1\,2}$, $E_{2\,3}$, and $E_{3\,1}$ represent the line voltages and I_1, I_2, and I_3 represent the line currents. The voltage $E_{2\,3}$ used for the voltage coil of the right hand element is designated as E_R on the vector diagram and the voltage $E_{1\,2}$ used for the left

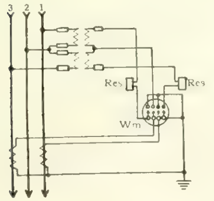


FIG. 88 MEASURING REACTIVE VOLT-AMPERES
Of balanced three-phase Loads.

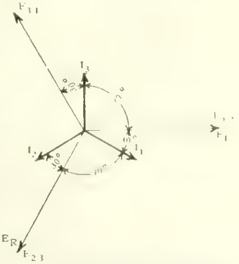


FIG. 89 BALANCED LOAD AT UNITY POWER-FACTOR
Of circuit shown in Fig. 88.

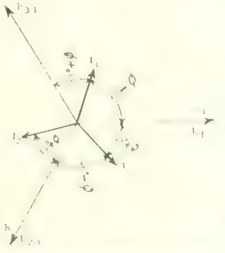


FIG. 90 BALANCED LOAD AT ANY POWER FACTOR
With connections shown in Fig. 88.

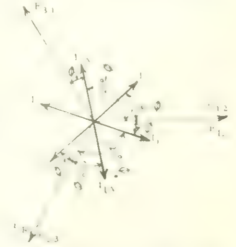


FIG. 91 SINGLE-PHASE LOADS AT ANY POWER-FACTOR
Of circuit shown in Fig. 88

hand element is designated as E_L. The vector diagram shows that the current is 90 degrees out of phase with the voltage in both elements, and therefore no measurement is indicated by the wattmeter, which is correct.

In Fig. 90 is shown a vector diagram for a balanced load at any power-factor where the current lags by an angle ϕ. The line currents are then $30° + \phi$ behind the line voltages. In the right hand element I_1 is $90° - \phi$ ahead of E_R and the measurement is $E_R\, I_1 \cos (90° - \phi)$ or, omitting the sub-figures, $W_R = E\, I \cos (90° - \phi) = E\, I \sin \phi$. Likewise in the left hand element I_3 is $90° - \phi$ ahead of E_L and the measurement is $E\, I \sin \phi$. The sum of the measurements in the two elements $W = 2\, E\, I \sin \phi$ which multiplied by 0.866 is $1.73\, E\, I \sin \phi$ which is the correct expression for the reactive volt-amperes.

The polyphase wattmeter connected as in Fig. 88 will not measure the reactive volt-amperes of unbalanced loads correctly as can be shown in connection with the vector diagram in Fig. 91. The extreme cases of unbalancing will be considered where single-phase loads are taken off between any two of the line. I_1 and I_2 represent the line currents when the single-phase load is between line 1 and line 2, and are shown lagging by an angle ϕ. There being a current transformer in line 1 but not in line 2, the only measurement is in the right hand element. The current I_1 is 120 degrees ahead of E_R and the measurement in the right hand element $W_R = E_R\, I_1 \cos (120° - \phi)$ or, omitting the sub-figures, $W_R = E\, I \cos 90° + (30° - \phi)$ which, multiplied by 0.866, is $-1/4 \sqrt{3}\, E\, I\, (\cos \phi - 1.73 \sin \phi)$. This cannot be reduced to $E\, I \sin \phi$ and is therefore incorrect. If the current leads by an angle ϕ the measurement is $E\, I \cos (120° + \phi) = 1/2\, E\, I\, (\cos \phi + 1.73 \sin \phi)$ which multiplied by 0.866 is $-1/4 \sqrt{3}\, E\, I\, (\cos \phi + 1.73 \sin \phi)$. This result is somewhat different from that for a lagging current but is also incorrect.

A similar analysis will show that this connection gives incorrect readings for any unbalanced load.

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

To receive prompt attention a self-addressed, stamped envelope should accompany each query. All data necessary for a complete understanding of the problem should be furnished. A personal reply is mailed to each questioner as soon as the necessary information is available; however, as each queston is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply.

1004—Transformer Capacity—What horse-power in three-phase motors would three 15 kw, 220 volt, single-phase transformers carry; also two 15 kw, single-phase transformers connected open delta? A.H.A. (ILL.)

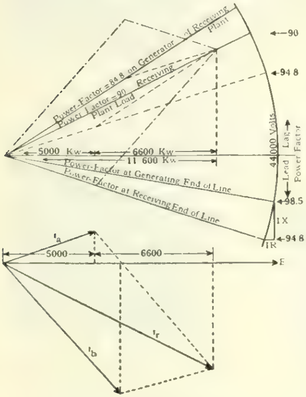
The capacity of three 15 kw, single-phase transformers connected three-phase is 45 kv-a. The capacity of two 15 kw single-phase transformers connected open delta is 30 × 0.866 = 26 kv-a. The horse-power of motors that can be continuously fed from the transformers equals the kv-a capacity of the transformers, times the motor efficiency, times the power-factor (both expressed decimally), divided by 0.746. Thus assuming a motor efficiency of 90 percent and a power-factor of 85 percent, the two 15 kw transformers connected in open delta would carry 26.7 hp of motors. However, as industrial motors are very seldom operated at full rated load continuously, it is customary to install a much smaller transformer rating than the combined ratings of the motors. This is especially true where a number of motors are fed from one bank of transformers, in which case the transformers have frequently one-half to as low as one-fourth the kw ratings of the motors fed therefrom. This depends entirely on the diversity factor of the motors. C.R.R.

1005—Compound Wound Exciters—Please tell me why a compound wound direct-current generator is nearly always used for exciting the fields of alternators. As I understand it, the series winding is to keep up the voltage as the load comes on, in a direct current generator when it is used for power and lighting loads. But I do not understand what there is in alternating-current generator field coils that can make the series winding of the exciter increase the voltage of the exciter. If the alternator is running at a certain speed and the rheostat in the exciter field is on a certain point, and more load is put on the alternator, it will bring down the voltage of the latter and before it can be raised again the voltage on the exciter will have to be raised by cutting out resistance on the exciter field. In this case what good does the series winding of the exciter do? Is a shunt wound exciter just as good for this purpose as the compound? The reason for this question is: We have a compound wound exciter for one alternator from which we charge automobile batteries also. Suppose the machines are running at the proper voltage and we put on a battery, with the proper resistance, the extra current passing through the series coils on the exciter boosts up the voltage and sends more current through the alternator's fields, raising its voltage, which is objectionable. By inserting more resistance in the shunt field everything is brought back to normal. If we had a shunt wound exciter would not the voltage keep approximately steady when we cut in the battery, as all the current would be taken from the armature without increasing the field flux, thereby not effecting the alternator's voltage except for lowering it a little? Is there any disadvantages in using a shunt wound exciter when there is only one installed? E.B. (ALBERTA)

Though compound wound direct current generators are often applied to exciter work, it is by no means universal to use compound wound rather than shunt wound machines. In the smaller sizes, compound wound generators only are kept in stock; the desire to use stock machines probably accounts for the use of compound wound exciters in many cases. In general, when automatic voltage regulators of the Tirrill type are used, anything more than a slight amount of series field will adversely affect the operation of the equipment, as the effect of the series field winding is to slow down the rate of change of the exciter field flux as the automatic regulator changes the exciter field current. This is particularly true if commutating pole machines are used. As a result it is often necessary to shunt a large part of the current from the series winding when automatic voltage regulators are used. The load upon the alternating current generator cannot, in itself, change the exciter voltage, which can only be controlled by adjusting the exciter rheostat, and thus to change the alternating-current voltage requires either a change in the excitation of the exciter or a change of the resistance in the main field circuit. In the case such as you describe, a shunt wound generator would probably be better than the overcompounded generator you now have. However, the best method of overcoming the present difficulty would be to shunt enough current from the series field winding to give a flat regulation or as near flat as possible. With the extra battery load upon the exciter, care must be taken that the shunt field winding does not become too hot, with the weakened series field. If there is a relatively high resistance series with the battery, when it is connected to the exciter leads, the alternating-current voltage can be held constant by cutting out this resistance and adjusting the exciter rheostat simultaneously. C.L.

1906—Transmission Power-Factor—We have two power plants, one the generating plant on which the load is 9000 kw at 90 percent power-factor, and the other the receiving plant, on which the load is 6600 kw at 90 percent power-factor. It is proposed to connect these two plants with a 44 000 volt transmission line and deliver to the receiving plant 5000 kw, and the voltage on both plants is to be held the same, i. e., 4150 volts on the bus-bars, or 44 000 volts at each end of the high-tension side. The question has come up as to the power-factor, that would result on the generators at the receiving plant. Fig. (a) shows a solution of this problem which I wish you would criticise. The line resistance and reactance was added to that of the transformers on each end, and the line figured out for a load of 90 percent power-factor. This, of course, gave a drop at the receiving end of the line. Now if the voltage is to be held constant at both ends, it was conceived that if this triangle was revolved down to the leading side until the small triangle of resistance and reactance coincided with the constant voltage circle, the power-factor at the generator and receiving ends of the lines could be determined. Now as the field strength of the alternators at the receiving plant must be increased to give the extra wattless current needed when the transmission line is tied in with the plant the current will be lagging with respect to the leading current in the transmission line. Therefore the line showing the power-factor at the receiving end of the transmission line was simply transposed at the same angle up to the lagging side of the diagram and a parallelogram combining this load of 5000 kw with a load of 6600 kw on the power plant, making a total load of 11 600 kw, but this load has its power-factor determined at 90 percent by the entire apparatus on it, therefore, it is the resultant of the incoming transmission line load and the generator load. As seen, this gives a generator power-factor of 84.4 percent lagging.

C.R.S. (PA.)


Power-Factor = 84.8 on Generator of Receiving Plant
Power Factor = 90 Receiving Plant Load
90
94.8
5000 Kw
6600 Kw
11 600 Kw
44000 Volts
Lag
Lead
Power Factor
Power-Factor at Generating End of Line
Power-Factor at Receiving End of Line
98.5
IX
IR
94.8
Ia
5000
6600
E
Ir
Ib

FIGS. 1906(a) and (b)

The plan for finding the power-factor at the generating station is approximately correct. There is a small error introduced because of the changing of the values of IR and IX, as the amount of current is changed while the vector is being rotated. In the illustration given, the error is very small, as the values of IR and IX were secured on the basis of 90 percent, and the power-factor, as determined by the construction, is approximately 95 percent. This means that the value of I used in determining IR and IX was five percent too large. After the determination of the power-factor of the current coming from the generating station, the remainder of the construction is faulty. A correct construction is shown in Fig. (b). E, the voltage at the receiving station is taken as a base. I_r is then the load current at the receiving station at an angle from E, such as to give 90 percent power-factor lagging. I_a is the current from the generating station at a power-factor of 95 percent leading, as determined by the first construction. I_r is then the resultant of two currents, one of which is I_a and the other I_b, which is the current from the generator in the receiving station. The construction shows that the angle between I_b and E gives 68 percent power-factor lagging, which is considerably lower than the value determined from Fig. (a). The same result is obtained if the vector representing the power-factor of the load from the generating station is left in its proper quadrant as shown in dot and dash lines in Fig. (a).

A.W.C.

1907—Harmonics in Transformers—Are harmonics given much consideration in the design of transmormers?

J.A.W. (OHIO)

Particular attention is given the harmonics in magnetizing currents and voltages of transformers intended for three-phase, star-star operation. In order to supply the proper third harmonic component of magnetizing current for star-star connections, tertiary windings are provided. It is generally not necessary to pay much attention to any harmonics except the third. See article on "Tertiary Windings" by J. F. Peters in the Journal for Nov. '19, p. 477.

J.F.P.

1908—Designs of Rotor Support of Vertical Water-Wheel Alternator—Are the arms which radiate from the lower guide bearing, and on which the air brakes are usually mounted, generally designed with sufficient strength to take the total weight of rotor, shaft, and turbine runner of vertical generating units?

R.E.G. (MONT.)

These arms are generally designed with sufficient strength to take the total weight of rotor, shaft and turbine runner.

R.A.M.

1909—Burning Insulation to Facilitate Removing of Coils—What objection is there, if any to the burning of the stators of small motors to facilitate the removal of coils?

W.R.V. (GA.)

The heating of the iron may cause the laminations to become fused or they may be oxidized and forced apart. Also other mechanical injury may be done to the assembled stator, such as distorting the punchings, warping the castings, spoiling the bracket fits and even burning the enamel off the punchings, producing a short-circuit path for eddy currents. The best way to facilitate stripping is to heat the stator in a baking oven until the insulation is soft. The winding may be stripped out with minimum effort while the machine is still warm.

T.P.K.

1910—Rating of Reactance Coils—How are reactance coils rated; for instance, just what is meant by the following nameplate data, 2200 volts, 300 amperes, 33 kv-a? What effect may be expected from such a coil on a 2000 volt, single-phase circuit in the event of a short-circuit on the line?

C.S. (QUE.)

Reactance coils are rated by the normal current and line voltage for which the reactor was designed; by the current which the device is required to stand under short-circuit and by the kv-a absorbed by normal current. It is necessary to know the size of the feeder, the relation its capacity bears to the capacity of circuit breakers and the generator capacity in order to know what effect may be expected from the above mentioned reactance coil in a 2000 volt single-phase circuit in the event of a short-circuit on the line. For further details see the article on the application of current limiting reactors by H. H. Rudd and W. M. Dann in the Journal for June 1916, p. 281.

J.F.P.

1911—Overlapping of Phase Groups—Is there any gain in the efficiency of a motor or any other gain by allowing the coils of adjacent groups but different phases to overlap?

W.R.V. (GA.)

The overlapping of phase groups is a condition obtained by using coils having a throw less than a full pole pitch. This results in part of the coils of a phase group occupying the same slots as coils of another phase. This arrangement has a distinct advantage, if it is not carried too far, and is nearly always used on induction motors. Using a short throw or chording a winding reduces its effectiveness, but the reduction is very slight for small changes, the effectiveness of the winding being decreased according to a cosine law. However, the length of the end winding depends directly on the throw of the coil, so by making a compromise, it is possible to save considerable copper in end windings without a prohibitive decrease in the effectiveness of the winding. In designing a motor, it is necessary to obtain certain torque conditions, requiring that the winding have a certain definite number of turns per coil. Oftentimes, in order to obtain the required conditions, the turns per coil do not come out a whole number. In this case it is customary to use the next larger whole number and reduce the effectiveness of the winding to the required value, by using a short coil throw. Chording has also the advantage of improving the shape of the revolving field, giving flux conditions approaching those which would be obtained by using a full pitch winding with a larger number of phases. H.L.S.

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

AUGUST 1920

Field Winding Diagrams for Railway Motors—II

Under the above heading, Part I, (June 1920) the five different schematic arrangements of main and commutating field coils were shown in Figs. 1 to 5, and a typical diagram of connections of a modern commutating pole motor with four commutating field coils in Fig. 6. In this article, typical diagrams of the remaining three types of non-field control motors are shown.

In general all of the types of windings shown come under the following main headings:—

1—Non-commutating pole motors—which includes all of the old type of motors.

2—Commutating pole motors—which includes all the more modern types of motors.

On all railway motors (non-commutating and commutating pole type) there are four main field coils. In general these four coils have the same number of turns on each coil. On a few machines, however, this is not true, as the top and bottom coils have more turns than the two side coils, this being done to shorten up on the gear centers of the motor. On commutating pole type railway motors four commutating coils are most commonly used. In this case each coil has the same number of turns. With small size motors, owing to the mechanical limitations in design, and to make use of some electrical advantages, the necessary commutating magnetic flux is obtained by the use of two or three commutating coils. When using two or three coils, each coil of each combination has the same number of turns.

The various types of coils and locations of leads shown on the diagrams are classified in Table I. There is no standard arrangement of leads that can be applied to all field windings. In the more modern motors it has been necessary to place the leads at the end of the coils on account of lack of clearance for the commutating coils. By the use of open and crossed coils the wiring around the frame is simplified. This method requires carrying in stock two types of coils, with the added chance of getting coils mixed in replacing damaged coils. To provide against this, these coils are marked with an "X" for crossed coils and an "O" for open coils.

It is considered best practice in connection with all modern motors and is recommended for old motors, to use cables coming out of the body of the coil instead of the heavy brass terminals, to make the wiring around the frame connections. The main objection to the use of terminals is that they are more likely to break off, due to vibration, or to develop a loose connection and burn off the lead. Another disadvantage is the difficulty of properly insulating the terminals after the connection is made.

JOHN S. DEAN.

TABLE I—TYPES OF FIELD COILS AND LOCATIONS OF LEADS

Figure	Main Coils		Commutating Coils	
	Type of Coils	Location of Leads	Types of Coils	Location of Leads
6	Open and crossed	Front	Open	Front
7	Open	Side	None	None
8	———	Front and rear	Open	Front
9	Open	Front	Open	Front

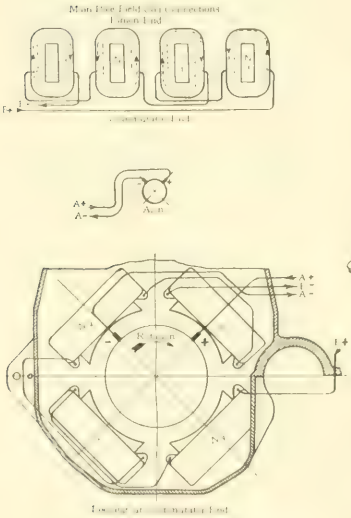


FIG. 7—NON-COMMUTATING POLE MOTOR, FIG. 1 (SCHEMATIC)

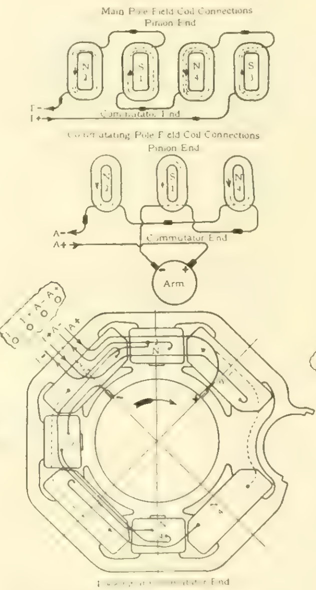

Main Pole Field Coil Connections
Pinion End
N 2
S 1
N 4
S 3
F-
F+
Commutator End
Commutating Pole Field Coil Connections
Pinion End
A-
A+
Commutator End
Arm
Looking at Commutator End

FIG. 8—MOTOR WITH THREE COMMUTATING FIELD COILS, FIG. 3 (SCHEMATIC) Dotted lines show connections at pinion end.

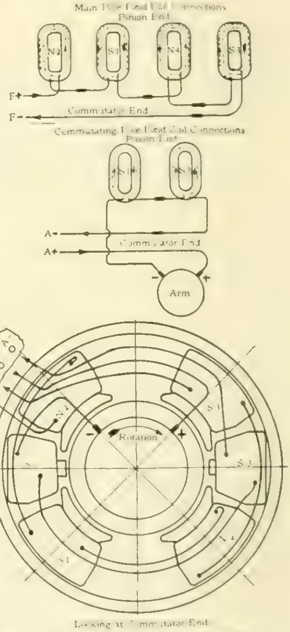

Main Pole Field Coil Connections
Pinion End
N2
S1
N4
S3
F+
F-
Commutator End
Commutating Pole Field Coil Connections
Pinion End
A-
A+
Commutator End
Arm
Rotation
Looking at Commutator End

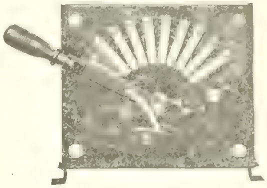
FIG. 9—COMMUTATING POLE MOTOR WITH TWO COMMUTATING FIELD COILS, FIG. 4 (SCHEMATIC)

Ward Leonard

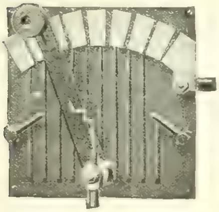
Field Rheostats

Vitrohm Field Rheostat
8 in. diameter [illegible] 4 in. deep [illegible] step

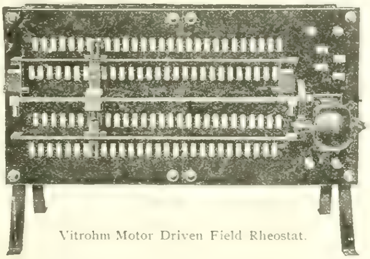
WARD LEONARD
VITREOUS ENAMELLED RESISTOR UNIT
8000 Ohms
VITROHM



Type P. F. Vitrohm Rheostat
for low voltage generators.

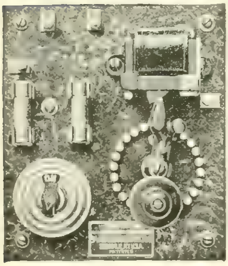


Vitrohm Field Rheostat
for low voltage self-exciting
generator.



Vitrohm Motor Driven Field Rheostat.

Front View of 6 in. Vitrohm
[illegible] Field
Rheostat.



Starting Panel with Vitrohm
Field Rheostat for small
motors.

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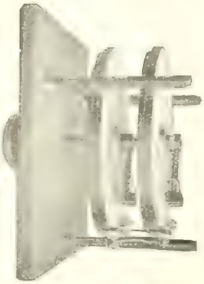

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NATIONAL SAFETY SECTION

BOILER ROOMS

The following suggestions for maintenance and operation of boiler rooms are supplemental to local laws and ordinances, and the requirements of insurance companies. Attention is directed to the Boiler Code of the American Society of Mechanical Engineers and compliance with that code is recommended.

ORDER

In carelessly kept boiler-rooms the stumbling hazard is present in an aggravated form. Loose coal is a prolific cause of accidents. If firing tools are carelessly placed, one is almost certain to find in the same room, steam hose carelessly thrown down, wheelbarrows left projecting from dark corners, skids or planks behind the doors, and scores of other hazards inviting accident. Space from the furnace door to wall of room, other boiler setting, coal pile, or other obstruction, should be sufficient to permit withdrawal of the longest tool without hazard or inconvenience. If there is sufficient space beside the boiler, racks for tools should be provided on the boiler setting. Other suitable places may be the front of the setting, the wall of the room in front of the boiler, or the back of the boiler setting. Tool racks must be substantially built. They must prevent falling of tools and must not form obstructions. Racks recessed in walls are usually satisfactory. The practice of allowing tools to lie on floor is inexcusable.

EXITS

Two or more ways of exit should be provided from boiler rooms. The exits should be plainly marked and illuminated and the exit doors should swing out from the room.

LIGHTING

Boiler rooms are often slighted as regards both lighting and ventilating. Coal seems to suggest dirt, darkness, and disorder to the unthinking, but the visitor to this department is often struck by the painstaking efforts of the grimy firemen in their attempts to secure order and safety.

ELEVATED RUNWAYS

Elevated runways should be strongly constructed and adequately railed and protected. Entrance should be by metal or concrete stairways. (See National Safety Council's "Safe Practices—Stairs and Stairways.") Flooring of runways should be of grating type rather than of solid construction—the liklihood of accumulating coal dust on closed construction influencing the choice. Several levels of runways may be found in properly equipped and up-to-date boiler rooms, whereas, in the older construction, ladders are depended upon to reach the several points necessary in the course of the day's work. In addition to stairs and runways, chain or indirect control of several of the vital valves and safety appliances will be found advisable.

FLOORS

Brick flooring is sometimes recommended in handbooks on this subject. While it is a non-conductor of heat, it lacks smoothness and consequently does not lend itself to efficient operation. Types of floors may be different around boiler settings and under coal piles. Floors immediately around boilers should be of metal plate with abrasive surface or of concrete. Under the coal pile, concrete will afford suitable footing and will not interfere with use of shovel. Metal plate or grating should be used where ash conveyor is let into floor. Non-slip surface should be used. If inclines are used, construction should conform to that outlined under "Inclines" in "Safe Practices—Stairs and Stairways."

STORAGE OF FUEL

If coal is dumped from railroad cars into a hopper, a metal grating should be used near the top of the hopper to prevent a workman falling into it. Grating should be of such character as to permit efficient handling of coal and at the same time to afford maximum protection for workmen. A workman entering a bin should wear a safety belt and life line. Upper end of life line should be securely attached to stationary object. A companion workman should keep line adjusted short enough to prevent man in bin from being drawn under material. Coal is often cribbed to a height of several feet and, between cribbings, retaining planks are placed for the retention of excess coal, and then more and still more coal is piled on top of the last. Valuable space is sacrificed, the stumbling hazard is multiplied and frequently no beneficial result is obtained. In ordinary practice only a sufficient amount of coal for the period between replenishments—with a moderate reserve—should be allowed in the room.

WATER SUPPLY

If a reservoir is used as a water supply, it should be fenced to a height of at least seven feet. Eighteen inches or more should be allowed between fence and curbing for use in cleaning or emergency work. Gates should be securely locked and admittance refused to any except specified workmen. If side walls of reservoir are perpendicular or slope is at a sharp angle, a safety grab rail at about water level will, at times, prove invaluable in preventing accidents. The usual rail guards are not sufficient protection for reservoirs. A fixed ladder or stairway should be installed—this to reach low-water mark—as a means of escape in case of accident.

FROM WATER SUPPLY TO BOILERS

In the economizer, the temperature of the water is frequently raised to nearly that of the boiler. As the economizer is under the same pressure as the boiler, precautions should be taken to maintain and operate the economizer with the greatest care. The water should enter the boiler after passing through a check valve. A safety valve should be provided for each economizer. The boiler itself should conform to the A. S. M. E. code. Many engineers recommend that the tops of boiler settings be made flat so that the repairmen are provided with a rapid means of escape from tops of the boilers in an emergency, and with a safe route to travel in their work. This is done by filling around the drums or shells with an insulating compound, with four or five inches of concrete on top. If flat top settings are impracticable, a continuous walkway (with standard railings and toeboards) should be provided over each bank of boilers. The walkways, should be arranged so that steam valves and safety valves are accessible from them. Safety valves should not discharge across the tops of boilers. Direct the discharges upward and have them above the heads of men who might be working around them. When discharge pipes are carried through roofs, the outlets should be at least seven feet above the roof levels. Where discharges are not self-draining, open drains of non-corrosive material should be placed at the lowest possible points. These will insure against collection of water, and discharge of much hot water when valves open. Drains should be piped away from tops of boilers. Leaving the boiler and allied appliances, the steam passes through a triple-acting valve and an ordinary stop valve into the steam and on to the prime mover. Safe and convenient access to each valve should be provided (preferably two) by means of stairs or walkways equipped with railings. Sufficient headroom (at least six feet) and adequate illumination should be provided. Steam connections, valves, and main are all specifically set forth in the handbooks on boiler practice and will not be duplicated here. A full list of safety equipment will be found in the A. S. M. E. code.

NEW BOOKS

"Statistics in Business, Their Analysis, Charting and Use"—Horace Secrist. 137 pages, 30 illustrations. Published by McGraw-Hill Book Company. For sale by The Electric Journal. Price $2.00.

This book is primarily for use in schools of commerce, and for business executives. As the treatment is quite brief the subject cannot be discussed at any great length. Considerable space is devoted to methods of graphic analysis, but this method of presenting facts is not given in as great detail as in some other books on this subject. A good chapter is given on summarizing facts bringing out the use of index numbers for various commodities in which connection references is made to the author's book "Introduction to Statistic Methods."

"Inventions, Their Development, Purchase and Sale"—Wm. E. Baff. 230 pages. Published by D. Van Nostrand Company, New York City. For sale by The Electric Journal. Price $2.00.

The author brings out the point that an invention and a patent are not the same thing. Various methods are outlined and explained for making sales of inventions, raising funds for promotion, advertising for capital; also there are some suggestions on elementary contract laws and mistakes of inventors. A good rule for every inventor is "To get it down on paper with dates and witnesses."

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PERSONALS

Mr. Norman Bell, of the sales department of the Norma Company of America, has been made assistant sales manager of the company with headquarters at their Long Island City office.

Mr. Geo. D. Luther, agent for the Electric Storage Battery Company at Denver, has been transferred to represent this company at their Seattle office, 811 White Building.

Mr. Don C. Wilson, formerly electrical engineer for the Union Pacific Railroad, has been appointed assistant sales manager for the Edison Storage Battery Company, where he will have charge of the railroad department.

Mr. G. B. Rosenblatt, the western specalist in mining, smelting, electrometallurgical and electrochemical industries for the Westinghouse Company, has moved his headquarters from Salt Lake City to San Francisco.

Mr. G. W. Canney, service manager of the Westinghouse Electric & Mfg. Company at East Pittsburgh, has been transferred to the office of W. K. Dunlap, assistant to vice-president. To succeed him two service managers have been appointed. Mr. L. C. Richards, service manager of the New York office, has been transferred to East Pittsburgh and made electrical manager of service work in connection with all electrical apparatus. Mr. A. D. Hunt, of the South Philadelphia works, has been appointed steam service manager in charge of service of all steam apparatus.

Midstate Engineering Company, Westminster Bldg., Chicago, Illinois, has recently been organized to carry on consulting practice, specializing in industrial, power and plant engineering. Mr. R. J. Gaudy, formerly of the Sessions Engineering Company, will have charge of the enginering work and Mr. J. H. Milliken, formerly of the Electrical Engineers Equipment Company, will have charge of the equipment and commercial division activities of this organization.

A. H. Grayburn, who has been connected with the treasurer's department of the Westinghouse Electric & Mfg. Company for nine years, has been made assistant secretary and assistant treasurer of the Norma Company of America, Long Island City, New York.

F. L. Easton has been appointed manager of the Denver district office of the Economy Fuse Company of Chicago, with headquarters at 205 Commonwealth Bldg. Mr. Easton succeeds Mr. R. M. Olsen, who resigned recently.

Mr. F. B. Kirkbride, vice-president of the S K F Industries, Inc., has been elected president of this organization to succeed Mr. B. G. Prytz, whose resignation was accepted on account of his having been elected managing director of the Parent Company with headquarters at Gothenburg, Sweden.

Mr. R. Roth, formerly of the Lewis & Roth Corporation of Philadelphia, has resigned to become sales manager of Schweitzer & Conrad, Inc., of Chicago.

Mr. J. L. Ray, Manager of the Pittsburgh Office of the Western Electric Company, has been transferred to the New York City office as power apparatus sales manager.

Mr. E. L. Sessions, president of the General Devices & Fittings Company, has resigned from this organization to devote his entire attention to the Sessions Engineering Company of Chicago, owing to the continued growth of the latter organization.

Mr. W. R. Marshall has been appointed manager of the industrial division of the New York City office of the Westinghouse Electric & Mfg. Company, succeeding Mr. H. A. Pratt, who resigned to become sales manager of the Atlantic Elevator Company of New York.

Mr. D. H. Colcord of the publicity department of the Westinghouse Air Brake Company, Wilmerding, Pa., has been appointed advertising manager of the Square D Company of Detroit, makers of safety switches and similar devices.

NEW BOOKS

"Technical Writing"—T. A. Rickard. 178 pages. Published by John Wiley & Sons Company. For sale by THE ELECTRIC JOURNAL. Price $1.50.

This little book by the editor of the *Mining and Scientific Press* of San Francisco and formerly of the *Engineering and Mining Journal* of New York, is based on a series of lectures delivered to engineering classes at the University of California. The book is filled with good and bad examples of technical writing, most of them naturally being examples from the mining industry. The subject is discussed under general appearance, clearness, precision, superlatives, relative pronouns, prepositions, hyphens and compound words, slovenliness, construction of sentences, composition and style, and will well repay any engineer who desires to polish up one of his most effective tools—his ability to express himself clearly and concisely.

"Direct-Current Motor and Generator Troubles"—Theodore S. Gandy and Elmer C. Schacht. 274 pages, 107 illustrations. Published by McGraw-Hill Book Company. For sale by THE ELECTRIC JOURNAL, Pittsburgh, Pa. Price $2.50.

The object of this book is to present simple and effective methods for tracing and remedying difficulties in direct-current motors and generators. As the authors state, many books have been written on how motors and generators run but a vast army of operators are even more interested in why they do not run correctly. In addition to the discussions which would naturally be included under such a heading, sections are devoted to erection and assembly, also direct-current switchboards, with final chapters on methods of testing and useful data.

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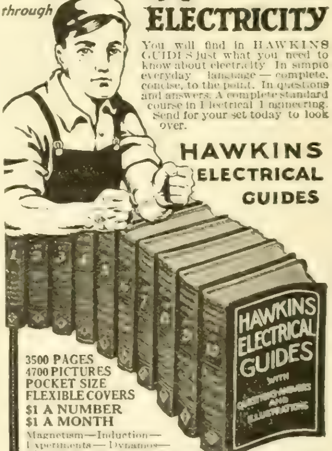

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THE ELECTRIC JOURNAL

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The Growth and the Accomplishments of the Assoc. of I. & S. E. E.

B. W. GILSON
President

THE growth of the Association of Iron and Steel Electrical Engineers has not only been great numerically, but the improved character of the papers presented and the good accomplished has been phenomenal. In 1907, this Association was organized with twenty-eight members and in January 1920 it had 1000 members. From January first to September first this year we have taken in 134 new members, making the total membership 1134.

In the beginning, we thought that an attendance at the monthly meetings of from twenty to thirty men was excellent, whereas we now have at these meetings an attendance of from two to three hundred men and the latest joint meeting of the Cleveland and Pittsburgh Sections was attended by 650. The sectional growth has greatly exceeded our expectations. In the early days of the Association only one section was organized. We are now operating five large and flourishing sections and within the next year we expect to get a sixth section started.

B. W. GILSON
Electrical Superintendent, Ohio Works, Carnegie Steel Co., Youngstown

The proceedings of the Association were first issued only one each year, while today we have an Association Journal, issued each month, with a combined book of the yearly proceedings at the end of each year. We do not consider the monthly journal as a trade paper, since the articles contained therein are both technical and practical, and the records and explanations of the electrical equipment are such that they can be easily read and understood by the non-professional man. The character of all the papers presented before this Association has greatly improved and I want particularly to call attention to two of the principal papers presented during the past year. A paper entitled "Electrical Features of a Modern Steel Plant" and another entitled "Steam versus Electric Driven Mills", are of particular importance. The great value of the first is due to the fact that it takes up the electrification of a steel mill from the ore pile to the finished product, giving motor sizes, power requirements, tonnage rolled and much valuable information for the steel mill operator. This is the first time, to our knowledge, that a subject of this kind has been so thoroughly developed in the form of an Association paper, giving such a large amount of valuable information and data. The second paper is also of exceptional value in that both sides of this question of steam versus electric drive are thoroughly discussed by prominent engineers, who are the best authorities in this country on steam and electric drives. The conclusions arrived at in this paper are only the beginnings of the advancement of electrification of iron and steel mills. We feel that the papers and the discussions of this Association have proven to be of far greater value to the steel mill engineers than the highly scientific treatises seen in the proceedings of some of the older societies.

The influence of the Association of Iron & Steel Electrical Engineers extends not only to every steel mill center in the United States, but also to those of every foreign country; so much so, that the steel mill men in foreign countries are rapidly affiliating themselves with our Association as active members. We now have enrolled as members, engineers from England, Australia, France, South Africa, Scotland, Mexico, Japan, Canada, India and South America. Largely due to the interest these men take in the activities of the Association, we feel that there has been a noticeable increase in the exports of electrical equipment from this country.

A further reason for the rapid growth of this Association is the spirit of fellowship, intensified by the monthly gatherings and the inspection trips or tours of various steel mills. Great good is accomplished by these visits to the different plants, as they allow operating men to see how the other fellow installs his apparatus and also the type of equipment he uses. In fact so much good has resulted from previous inspection trips that, in the future, larger trips of this kind have been planned.

The Fourteenth Annual Convention of the Association of Iron & Steel Electrical Engineers, will be held at the Hotel Pennsylvania, New York City, September 20th to 24th, inclusive and the prospects are that this will be one of the most successful and largest conventions that we have ever held. One of the most interesting features of the convention this year is the exhibition of apparatus of the various manufacturers. In previous years, the electrical manufacturers' exhibits were scattered through the various hotel rooms and it was difficult to locate and inspect them all. This year all of the exhibits have been confined to booths located on the floor where the technical sessions will be held. We wish to emphasize the fact that these exhibits provide an educational feature in conjunction with the technical sessions, and should prove of great value to the steel mill operator. The manufacturers' apparatus is not exhibited simply to fill up space, but as it represents the latest and the best equipment now on the market, it should prove of great benefit.

In general, the papers to be presented at this convention will deal with the complete electrification of a steel plant with discussions by engineers who represent every steel mill center of any consequence in the United States. All of the papers on the convention program represent the earnest effort and hard work of the authors.

For the future of the Association, the scope of our society is unlimited. The Association is young and I hope, within the next three or four years, to see societies established in all foreign countries, so that by the interchange of international ideas we can progress more rapidly. The members of this Association must not lose sight of the fact that our success is due in a large measure to our specialization in the application of electricity to the iron and steel industry, and we do not want to depart from this fundamental principle of our Association.

During my term of office, I have been greatly pleased at the high degree of co-operation given by the officers and members in every activity for the benefit and welfare of the Association. I want to take this opportunity of acknowledging, with thanks, the able assistance and earnest effort which my co-workers, the officers and members of this Association, have always given, and I feel that it is to them that the success and high standing of the Association is largely due.

The Electric Motor in the Steel Mill

G. E. STOLTZ
Steel Mill Engineer,
Westinghouse Electric & Mfg. Company

EARLY in the sixteenth century, Ponce de Leon led an expedition to Florida in search of a fabled fountain of perpetual youth. The modern electric motor would seem to have attained the attribute he sought, as it may truly be said to have continued youth, its efficiency remaining the same over a wide range of load, regardless of its years of service. The automobile or steam engine may have excellent guarantees of economy and will meet them under the most advantageous conditions. On a long trip with the engine in good condition, an automobile may make, say, seventeen miles to the gallon, but the owner by no means expects such a record as a yearly average. A steam engine driving a rolling mill may have very good economy at 80 to 100 percent load, but the requirements of such mills vary from one-quarter load to load and a half, so that it is impossible to take advantage of the engine's best economy at some particular load. In addition, the constant wearing of the piston rings and any loss of adjustment of the valves will increase the steam rate of the engine, even at the most advantageous load. The efficiency of an electric motor is high from fractional load to an extended overload, and there are no wearing parts that tend to change this characteristic with service. The first motors installed on main rolling mills were two 1500 hp direct-current adjustable speed motors. Their efficiency remains practically the same, whether carrying one-half load or one and one-half load; whether they are running at full field speed or with weakened field. This feature of their performance has remained constant throughout their entire period of service, which dates back to 1907.

This characteristic of constant efficiency and the possibility of transmitting electric power to all parts of a plant, whether remote or near to the source of power, with equal economy, has contributed greatly to make the electric motor the universal agent to replace manual effort.

The electric motor is not only finding new applications in the steel mill industry, but the tonnage output of iron and steel doubles every ten years, requiring many new plants, nearly all of which are being equipped for electric drive throughout. In 1918, thirty-nine million tons of pig iron were produced, having a volume sufficient to build two solid pyramids the size of the great pyramid of Cheops.

At the present time the electrical manufacturers produce annually thirteen million dollars worth of apparatus for the steel industry, which, if manufactured in one plant, would require an organization comparable to that of some of our large steel plants. If the apparatus completed in a year were loaded at one time, one hundred train loads would be required to make the shipment.

In recent years, the position of the electrical manufacturer has changed from that of exploiting electric drive in the steel mill industry, to one of straining every effort to produce sufficient apparatus to meet the growing demand. This simply indicates that the steel companies are planning to drive all their mills electrically, so as to utilize all their steam in economical generating units, and thereby provide a margin of economy, which will enable them to sell steel at a profit when the time comes that their customers will more closely scrutinize prices.

The Regulation of Electric Furnaces

C. B. GIBSON
Manager, Metallurgical & Electrochemical Section,
Westinghouse Electric & Mfg. Company

THE metallurgical industry has grown quite rapidly during the past few years. While this expansion was stimulated largely by war conditions, the fact that this country possesses substantial amounts of almost all the necessary raw materials, together with almost unlimited water power resources, gives assurance of the future and permanency of the industry. Along with this expansion have come new and improved chemical methods and processes which, in turn, have involved newer and broader applications of electricity and in some cases the development of entirely new apparatus. As a typical example, the enormous expansion in the iron and steel industry during the past few years, the increasing demand for alloy steels and the corresponding demand for ferro-alloys, have greatly increased the use of electric steel melting, refining and ferro-alloy furnaces and their products.

Refinements in the construction of the electric furnace and its auxiliary equipment are continually being made, with a view of greater tonnage output and economy of production. Possibly one of the most important improvements from the standpoint of the auxiliary equipment has been in the devices for controlling the position of the electrode, so as to keep the working conditions of the furnace as uniform as possible. The day of hand regulation of electric furnaces is past, and automatic regulation is now used universally. Among the recognized advantages of automatic regulation are—large saving in labor costs, an appreciable reduction of the time of getting out a heat and more efficient utilization of the current input to the furnace, due to the steadier furnace conditions.

The type of regulator described by Mr. Allen in this issue embodies, in addition to the above advantages, many salient features which should particularly commend it to the furnace operator. These features permit the use of faster electrode speeds without hunting or overtravel and eliminate any possibility of one electrode getting down into the bath of molten metal, thus raising the carbon content, which is often objectionable. Another feature which should particularly commend the regulator is its simplicity and ruggedness. It is expected that this regulator will mark a new era in furnace operation.

Maintaining a balanced load on all the phases of a polyphase system, and keeping a fairly constant voltage, at any adjustable value, regardless of wide fluctuations of load, are both important to the furnace operator, as they affect his relations to the source of power supply and the quality of his product. The various methods of balancing the furnace loads are discussed in detail by Mr. Evans, in this issue. We believe his article is the first published analysis of this interesting and important problem.

Various types of voltage regulators, based on the principle of varying the high-voltage taps of a transformer, have been in use for a number of years. In practically all these, comparatively few steps of voltage were available. On the other hand, the standard induction regulator was not applicable, except in the smaller capacities, on account of limitations in size and current carrying capacity. Accordingly, a demand developed for a regulator of large capacity which would give a uniform voltage variation over a wide range. Such a regulator has been developed and is used for controlling graphite, carborundum, zinc and similar types of furnaces. It possesses many decided advantages over previous types. Since the power input is under the complete control of the operator, the furnace can be operated more efficiently, resulting in greater tonnage output and improved product with lower conversion costs. In addition the close control over the power supply circuit eliminates momentary peaks, which are not only objectionable to the power company but also to the user. There should be a wide application of this type of regulator for use with various types of furnaces.

Electric Drives for Steel Mills

BRENT WILEY
Assistant Manager, Industrial Sales Dept.,
Westinghouse Electric & Mfg. Company

THE GROWTH in the use of electricity in the steel industry during the past twenty years has been phenomenal. While formerly only a small percentage of the primary power was electric, it is estimated that seventy-five percent of the primary power of new mills installed during the last five years has included electric motors, and at present approximately forty-five percent of the total power used is electrical. The many improvements offered by the use of electricity, including almost every phase of steel mill activity, have assisted materially in the development of steel mill practice to its present high state.

Specially designed mill motors and magnetic controllers have reduced the necessary skilled labor to a minimum and made possible many automatic or self-controlled operations. The electric apparatus is of more durable and reliable design and the result has been improved design of mill, increased capacity, fewer shut downs, less repairs and safer working conditions. Motor drive for the main rolls has become almost universal practice during the last ten years. All types of mills have been electrified and motors have been designed to meet every requirement. The flexibility offered by electric drive in speed, layout of mill, method of drive and other details has been of direct benefit in improving steel mills. One of the principal advantages of electrification is that it permits the most economical power layout from the standpoints of generation, distribution, upkeep and reliability. It is a very flexible system in reference to future extensions, and the larger the plant becomes, the greater are the advantages to be gained.

The electric furnace is becoming a prominent factor in the melting and refining of steel and there are many indications that its use will increase rapidly within the next few years. It is thus evident that electricity plays an important part in both the design and operation of the steel plant. The questions of fuel economy, space required, tonnage of mills, and best method of melting and refining the steel are demanding more and more study. In the majority of cases these problems are best solved by the use of electricity.

Much credit is due the Association of Iron & Steel Electrical Engineers for the part which they have taken in making the application of electricity to the steel industry so successful. The close co-operation of the members has been very effective in developing a clear and practical analysis of steel mill problems, so that their solution has been accomplished with minimum delay and duplication of effort, and repeated mistakes have been practically eliminated.

Internal Heating of Generator Coils

B. A. BEHREND
Consulting Engineer,
Boston, Mass.

THE INTERNAL heating of armature coils has been a subject of great interest. This interest is due not solely to the enormous importance of a thorough knowledge of the phenomena and conditions prevailing within the insulation and affecting the life and security of the machine, but also to the great scientific and engineering interest which attaches to this problem. Messrs. B. G. Lamme, F. D. Newbury and their collaborators have done splendid pioneer work in this field, and their labors, while not yet completed, have added greatly to our knowledge of this intricate and important subject.

The measurement of temperatures on the outside of the insulation of the armature coils of large electric generators, especially of turbogenerators, has been common practice, and it has received, most unfortunately, the sanction of the Standards Committee of the American Institute of Electrical Engineers. It was thought that the temperature measured between the two coils in a slot, where the insulation is contiguous, would indicate accurately the temperature of the coil on the inside, as it was thought that the temperature drop through the insulation would be zero at this point, in view of the fact that the copper conductors of both coils form conjugate points in relation to the place where the temperature detector was located.

While this assumption would be correct if the copper of the two coils was at the same temperature, if there was no heat flow to the slot sides, and if the temperature detector was infinitesimally small, it is not accurate when the two coils are of unequal temperatures, when there is heat flow to the sides of the slots, and when the size of the temperature detectors is not negligible. This has been demonstrated experimentally as reported by Messrs. Newbury and Fechheimer, at the recent Convention of the American Institute of Electrical Engineers at White Sulphur Springs.

It may be helpful for those who have difficulty in comprehending the subject or who have the desire to bring it to the attention of laymen, to think of an armature coil in a turbogenerator as a person completely clad and covered with a felt suit similar to a diver's suit. The blood temperature of such a person might be uniform in any part, but the temperature measured on the outside of this felt suit, if a number of air currents were directed against it by means of jets, would vary entirely with the position and exposure of the temperature detector, and there would not be any definite relation between the temperature thus measured on the outside of the suit and the blood temperature of the person within. This is a good analogy to the copper coil completely covered with insulation. It appears quite evident that no device and no measurement of external temperatures can permit any direct inference as to the conditions prevailing inside the insulating wrapper.

Even the calibration of temperature detectors which are placed on the outside of the coil, by comparison with temperature detectors placed directly in contact with the copper, is unreliable and of little use. A fairly good idea of the average temperature of the armature copper may be obtained by resistance measurements of the coil itself before and after a heat run, but such measurements give only the average of the temperatures at different parts of the coil. Yet the placing of temperature detectors next to the copper is a very unsatisfactory proceeding and is to be discouraged, as it reduces the security of the insulation.

The recent contributions to this subject are among the most valuable experimental investigations that have been made relative to this matter.

Electrical Equipment for 60-Inch Universal Plate Mill

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THE NEW 60 inch Universal Plate Mill at the Sparrow's Point plant of the Bethlehem Steel Company, has been in successful operation for the past ten weeks, and inasmuch as it is the largest reversing electric driven universal mill in this country, electrical engineers will probably be interested in a brief description thereof, with particular reference to the main driving equipment.

Fig. 2 shows the layout of the mill, which is divided into four principal sections, furnace section, mill section, finishing section, and shipping section. A part of the mill section is separate from the mill proper, and housed in to contain the electrical equipment for the main drive, as well as for the auxiliary power and control equipment; also a part of the shipping section in a like manner contains the motor driven pumps for supplying hydraulic power to the mill, and in this pump house are located machine tools and mechanics for taking care of the mill repairs.

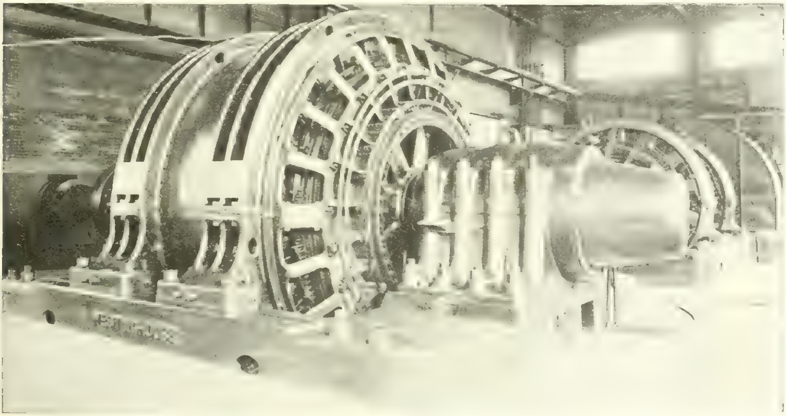

FIG. 1—5200 HP DOUBLE-UNIT REVERSING MILL MOTOR

Hot slabs direct from the 40 inch mill are loaded by means of a special tongs crane of 21 foot span onto cars which are shifted by locomotive directly into the furnace section of the mill. Cold slabs can also be sent to the mill on similar cars, which are loaded in the slab yard by one of two fifteen ton magnet cranes. Two ten ton slab charging cranes handle the slabs from these cars into and out of the heating furnaces, of which there are six, each equipped with four motor-operated doors and arranged for firing either oil or producer gas. Hot slabs from the furnaces are placed on an ingot buggy, operated by an electric motor driven winch and cable, and delivered in front of the mill, where an electric driven pusher discharges them onto the approach table, driven by a 50 hp mill type motor. From the approach table, the steel passes to the front live table and into the mill proper, which is a Morgan 60 inch two-high reversing unit, designed to roll 62 by 13 in. 10 000 pound slabs down to ⅝ by 60 in. plate in 21 passes. The horizontal rolls are 36 inches in diameter and revolve at a maximum speed of 100 r.p.m., while the vertical rolls are 21 inches in diameter and are geared to give as nearly as possible the same peripheral speed as the horizontal rolls. The lift of the top roll is 20 inches and the screw down is operated by two 80 hp mill-type motors located on the top of the pinion housing. The adjustment of the vertical rollers is taken care of by two 50 hp mill-type motors located on brackets attached to the pinion housing, through suitable gearing. For driving the main rolls of the mill a Westinghouse full reversing equipment is provided. A description of this equipment is as follows:—

The front and back live tables each consist of twenty-two rollers 16 in. diameter by 34 in. long mounted on 27 in. centers. Each of these tables is driven by a compound wound special slow-speed motor rated at 150 hp at 100 r.p.m.

After the rolling process is completed, the plate passes to the front straightener table, driven by a 50 hp mill-type motor and through a leveler, consisting essentially of leveling rollers driven by a 100 hp mill type motor with a 10 hp screw down motor auxiliary, and from this point passes to the finishing section of the mill, where by means of roller tables and chain transfers it is delivered to one of four straighteners. These operate like a long jawed vice, by means of 75 hp motors through suitable gearing, to straighten the plate edgewise.

After the straightening process is completed the chain transfer delivers the plate to the cooling beds,

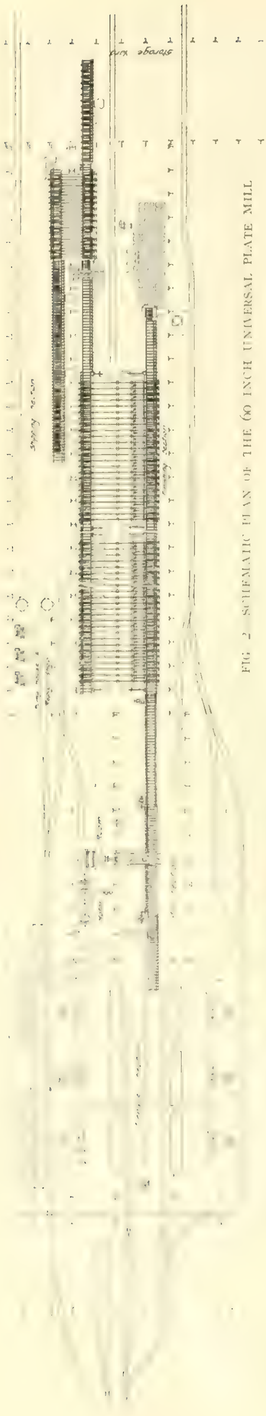
FIG. 2—SCHEMATIC PLAN OF THE 60 INCH UNIVERSAL PLATE MILL

where it is marked off preparatory to shearing. From here it is taken to the shear roller tables by means of the same chain transfer previously mentioned, and after the shearing is completed it passes over rollers into the storage yard or onto transfer tables into the mill shipping section, where it is discharged on the floor, by means of one of the four kick-offs, each operated by a 50 hp mill-type motor.

The crane equipment for the mill, in addition to the slab charges previously mentioned, consists of a two ton hoist for handling cinder from the furnaces, a 50 ton, 10 ton auxiliary, crane covering the mill proper and a 50 ton, 10 ton crane for the motor room, a 10 ton grab bucket crane for handling scale, two 15 ton cranes covering the finishing section, two 15 ton cranes covering the shipping section, and one double trolley 15 ton crane covering the shipping yard. By removing the side rolls the mill can be arranged to roll shearing plate and when it is desired to handle this product the plates, after going through the roller leveler, pass directly over tables to separate shears, arranged to handle longitudinal and transverse shearing.

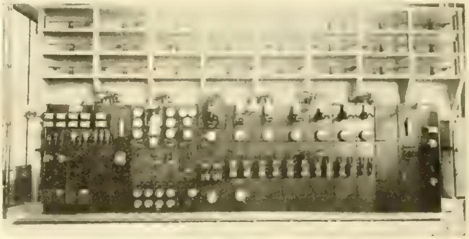
FIG. 3—SWITCHBOARD AND BUS STRUCTURE

Electrical energy is received at the mill over a double three-phase, 25 cycle, 6600 volt line, and part of the motor room is designed as a sub-station, as shown in Fig. 3, which gives a view of the 6600 volt busses arranged in a concrete structure, with the top of the oil switch mechanism showing directly underneath the bus, and in the foreground the main switchboard. The latter controls the incoming lines, step-down transformer bank for furnishing low-voltage alternating-current power to the hydraulic pump motors and the air compressor motor, main mill driving equipment, 1000 kw synchronous motor generator set for supplying 250 volt direct-current power to the mill auxiliaries, various direct-current mill circuits and a lighting transformer for taking care of the mill lighting.

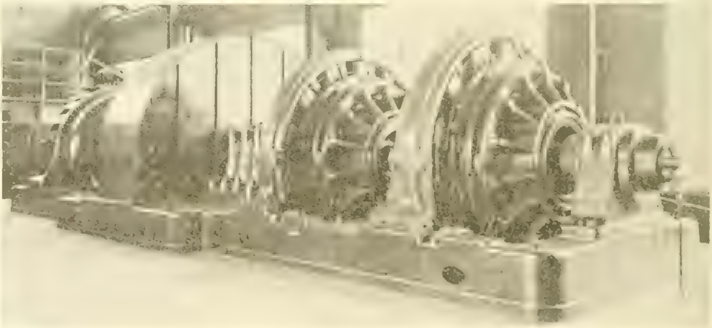
FIG. 4—6250 HP MOTOR-GENERATOR FLYWHEEL SET

The main mill driving equipment consists essentially of a main motor, flywheel motor-generator set, exciter, control, slip regulator, and air conditioner. Fig. 1 shows the main motor unit connected through a universal coupling to the top pinion of the mill. This unit consists of two motors, with their armatures mounted on a common shaft carried in two bearings, which are supported by low and well anchored pedestals. These bearings are of the self aligning type, water cooled, and arranged for lubrication from gravity oil feed. A heavy bed-plate supports the two pedestals and carries the motor field frames, which are heavy ribbed steel castings, split horizontally, so that the top half can be lifted off with facility for inspection and repairs. The feet are cast integral with the lower half of the frame and are provided with pads and set screws to permit accurate adjustment of the air-gap. The shaft is symmetrical and designed so that should the end which is connected to the mill become damaged, the armature can be turned end for end, and the other extension used. The mill end pedestal carries a heavy thrust bearing to absorb shocks, in case of an accident to the connecting spindle of the mill. The motor fields are provided with a double winding in addition to a compensating pole face winding. The function of one of these windings is to give a shunt characteristic while that of the other, in combination with a series exciter, is to give a series characteristic, making the unit as a whole the same as a compound wound motor. The brush rigging is mounted on heavy yokes which bolt to the sides of the field frames. There are 24 sets of brushes to each machine, and each set includes 5 brushes.

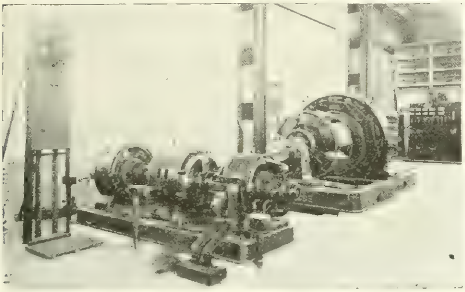

FIG. 5—50 KW EXCITER SET

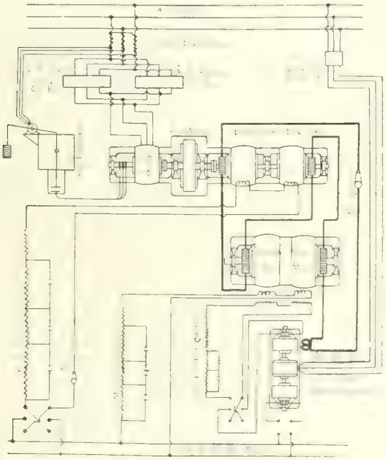

FIG. 6—SCHEMATIC DIAGRAM OF MAIN AND CONTROL CIRCUITS

The motor as a unit is rated at 4400 hp continuous, 35 degrees C. rise or 5200 hp continuous 50 degrees C. rise; full field r.p.m.-60, weakened field r.p.m. 100, maximum starting torque 1 960 000 ft. lbs.

The flywheel motor-generator set as shown in Fig. 4 is a five bearing unit, consisting of two 14 pole, compensated-type, 700 volt, direct-current generators, for supplying the energy to the main mill motors; one 150 000 pound flywheel unit, made up of three 25 ton solid cast steel wheels in enclosing case, mounted between two 20 by 54 inch bearings, and one three-phase, 25 cycle, 6600 volt wound-rotor induction motor. The generators are rated at 3650 kw, 35 degrees C. rise, or 4300 kw at 50 degrees C. rise. The driving motor is rated 5000 hp continuous 35 degrees C. rise; 6250 hp continuous 50 degrees C. rise. The speed of the set is 368 r.p.m. Total length of set 48 feet.

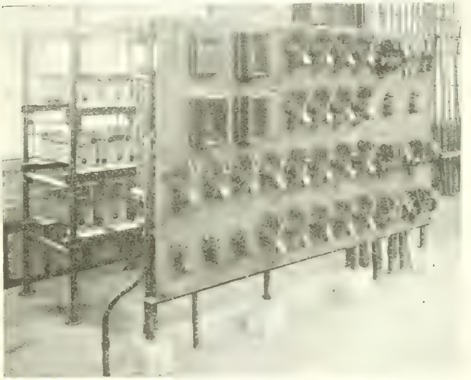

FIG. 7—ELECTROMAGNETIC CONTROL PANEL

In the foreground of Fig. 5 is shown the exciter, which is a three unit machine, all units being mounted on a common bed-plate. The two end units are direct-current generators driven by the center unit, which is a squirrel-cage 550 volt motor. One of these generators is a plain compound-wound generator and supplies constant potential for the main generator and motor fields, while the other supplies a variable potential, proportional to the armature current of the main mill motor, which gives the effect of series excitation on the main motor. This is accomplished by placing a very heavy winding on the field of this exciter, which is connected in series with the main mill motor armatures, as shown in Fig. 6. The exciter motor is rated at 110 hp, 40 degrees C. rise. The shunt exciter is rated at 50 kw, 250 volts. The series exciter is rated at 18 kw, 250 volts.

Directly in front of the exciter in Fig. 5 is the circuit breaker for opening the armature current to the main motor, while Fig. 7 shows the magnetic switch panels for handling the generator and motor field currents. This apparatus, together with the master controller and slip regulator, control the operation of the equipment as follows:—

With the set at full speed, the exciter operating and the master controller in the off position, the roll motor has full shunt field, and any motion of the master controller handle gradually excites the generator fields, producing a voltage across the armatures which starts the main motor revolving. Any variation in the load of the mill motor will vary the series field excitation, giving the effect of a compound motor, by means of the second field exciter and the second motor field winding previously described. The speed at which the roll motor runs is practically proportional to the impressed voltage, independent of load, up to the full field in both motor and generator; from this point the speed is increased by weakening the field of the motor.

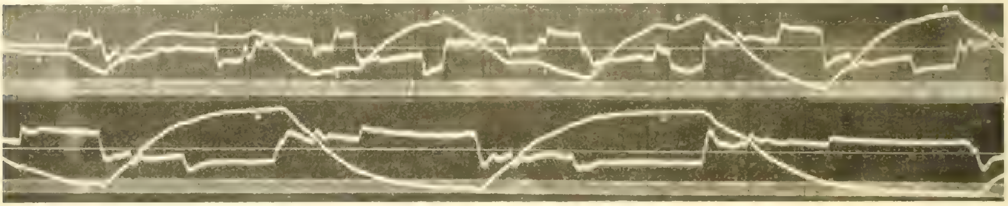

FIG. 8—ROLLING CYCLE ON THE 60 INCH MILL

With steel in the rolls, the load on the generator is much in excess of the average load over the entire cycle, and the function of the slip regulator is to allow the flywheel to supply the difference between the average load and the peak load. A series transformer is placed in the primary circuit of the flywheel set motor, and its secondary is connected to the small torque motor which operates the slip regulator. Any load causes the torque motor to exert a torque, tending to separate the electrodes of the slip regulator. When these electrodes separate, introducing resistance into the secondary of the flywheel set motor, the set slows down and permits the flywheel to give up part of its energy.

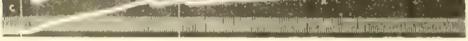

FIG. 9—REVERSAL TEST ON THE 60 INCH MILL

A—Line current; *B*—Motor speed; *C*—25 cycle timing wave

The slip regulator is also used for starting the flywheel set, which comes up to speed gradually after the primary circuit breaker is closed, and the no-voltage counter-weight on the regulator adjusted. The regulator is provided with a no-voltage release which opens the primary circuit breaker in case of failure of power.

The main reversing motor is brought to rest rapidly by means of dynamic braking, and by putting power back into the flywheel set a large proportion of the accelerating energy is reclaimed, helping each time to increase the speed of the set. A double-throw circuit breaker on the primary control of the main alternating-current motor is arranged to reverse the flywheel set motor should it become necessary to stop the set quickly.

For supplying forced ventilation to the reversing motor, a blower and air washer outfit is installed in the basement of the motor room, and the control on this blower motor is arranged so that any failure of forced ventilation to the motor will shut down the equipment and prevent the reversing motor from overheating.

A typical oscillogram in Fig. 8 shows the armature current *A* and speed *B* on the main roll motor during the rolling of a 5 by 28 in. slab, down to a 27 by 0.5 in. plate in 13 passes. Curve *C* is a 25 cycle timing wave.

The average power consumption of the main drive equipment over a series of tests for rolling 5 by 14 in., 1525 pound slabs to ¼ by 14 by 1176 in. plates is 56.6 kw-hr. per ton, not taking into consideration any idle running of the equipment.

Fig. 9 shows the main motor armature current, speed, and 25 cycle timing wave during the reversal of the motor from 67.5 r.p.m. forward to 67.5 r.p.m. reverse. From this it can be seen that the elapsed time for the complete cycle of speed change is 8.26 seconds, of which 3.18 seconds is consumed in deceleration and 5.08 seconds in acceleration. It should be noted that it is possible to speed up this cycle whenever increased output is required; however, under the present rolling conditions the operators are inexperienced and there is no necessity for any further increase and it is easier on the new equipment to make such changes very gradually as the demand for tonnage increases.

The Application of Adjustable Speed Main Drives in the Steel Mill

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THE adjustable speed set, comprising a wound rotor induction motor in conjunction with auxiliaries for dynamic speed regulation, fills a need as a main drive for some mills where a single direction of rotation is required with constant speed operation at adjustable speed values. There are two general types of speed sets, namely the constant horsepower type and the constant torque type. There are also in common use two general methods of speed regulation namely the rotary converter method and the Scherbius method. The principles upon which these sets operate have been set forth in some detail. It is the primary purpose of this paper to present some data pertaining to an installation of two rotary converter sets of the constant horsepower type as installed on a ten inch continuous skelp mill built by the Morgan Construction Company and installed at the Mark Plant of the Steel and Tube Company of America at Indiana Harbor, Indiana.

This mill comprises three main units, namely:

Roughing mill.
Edging stand.
Finishing mill.

The roughing mill consists of seven roll stands driven by a 2000 hp, 2200 volt, three-phase, 60 cycle Westinghouse induction motor with a six-phase wound secondary. On the same shaft with this motor is a 700 hp, compound-wound, direct-current auxiliary unit. A shunt-wound, four-pole, 0 to 520 kw, 0 to 630 r.p.m. rotary converter, for transforming the slip energy, is located nearby in the motor house. The synchronous speed of the main motor is 360 r.p.m. This speed may be reduced 35 percent, to 234 r.p.m., with dynamic regulation. The locked secondary voltage of the motor is 1210 volts. The rotary converter is rated at 0 to 568 volts. The secondary frequency at minimum speed is 21 cycles. The converter is a 25 cycle unit.

The mill layout is shown in Fig. 2. The roughing mill comprises the following stands:—

No. 1—Horizontal rolls.
No. 2—Edging rolls.
No. 3—Horizontal rolls.
No. 4—Horizontal rolls.
No. 5—Edging rolls.
No. 6—Horizontal rolls.
No. 7—Horizontal rolls.

No. 6 stand is connected to the main spindle. Stands No. 1 to No. 5 inclusive operate at reduced speeds through gearing. No. 7 stand operates at increased speed through gearing. The main drive motor transmits its power through a flexible coupling to a Falk herringbone-gear unit, having a ratio of 3.6 to 1. This gear is connected to No. 6 stand of the mill through a breaking spindle.

The steel received from the billet mill is reheated in a continuous type furnace, whence it is entered into the roughing mill by a push out bar and pinch rolls. After passing through the roughing stands in the order named, it enters the edging stand—No. 8 edging rolls. This stand is driven by a 160 hp Westinghouse adjustable-speed, direct-current motor, with a speed range of 250 to 500 r.p.m. by field control.

The finishing mill consists of three stands of horizontal rolls, No. 9, No. 10, No. 11 and a rotary shear. Belt drive is used for these stands to give a smooth finish to the skelp. The driving motor for this unit is connected to the main drive pulley through a breaking spindle. This drive comprises a 2000 hp, 2200 volt, three-phase, 60 cycle Westinghouse induction motor with six-phase wound secondary. On the same shaft with this motor is a 660 hp compound-wound, direct-current auxiliary unit. The synchronous speed of the main motor is 240 r.p.m. This may be reduced 33 percent to 160 r.p.m. The rotary converter is a four-pole machine rated at 493 kw, 0 to 593 r.p.m. The locked secondary voltage of the main motor is 710 volts. The rotary converter is a 25 cycle unit, running from 0 to 19.8 cycles and rated at 0 to 314 volts.

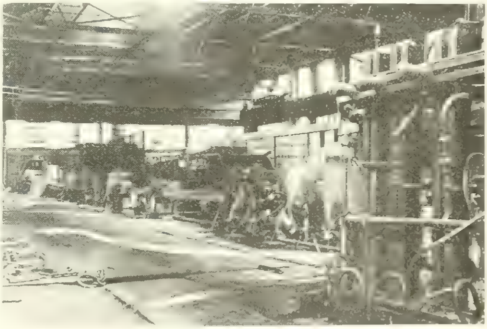

FIG. 1—10 INCH SKELP MILL
At the Mark plant of the Steel & Tube Company of America

Both the roughing mill drive and the finishing mill drive are equipped with switchboards for manual switching of the motor primaries, and for transferring the secondaries from resistance to dynamic regulation with the auxiliaries. The secondary resistances are connected three-phase star, with magnetic secondary control panels giving current limit acceleration. Both the roughing and finishing mill drives may be operated as simple induction motors, with the secondary resistance short-circuited. The roughing drive is operated in this manner the greater portion of the time. The speed of the edging rolls and finishing mill is then adjusted to give the proper speeds to obtain the desired loops between stands. Tests have been run on these drives with the mill handling both light and heavy orders. The results of tests representing the two classes of service are presented herewith.

Data were obtained to determine the loading, speed and power-factor for the roughing mill drive when running as a simple induction motor with short-circuited secondary. The load chart shown in Fig. 4 was obtained with the roughing mill rolling a heavy order, namely 7¾ by 2 in. to 7⅝ by 0.315 in., the finished product being 7⅞ by 0.175 in. The material rolled was Bessemer steel with 0.10 percent carbon content. This chart, taken with a slow paper speed (1.26 in. per minute), shows the nature of the load cycle. Between the load periods, when steel is in the mill, there are considerable periods of idling. These are necessitated by the fact that the furnace is unable to heat the heavier stock as fast as the mill can roll it. The rolling speed is determined by the finishing mill, which is operated at its minimum speed. The load chart shown in Fig. 5 was taken at a fast paper speed. It shows how the load varies over the cycle in rolling one billet. The chart has been analyzed to show where the steel enters and leaves the various stands. It is of interest to note that these points are quite clearly defined. As the steel enters the successive stands, the load is built up in steps. The load is maintained for several seconds while all stands are full, falling off as the steel leaves them in turn. The total time of the cycle depends upon the length of the billet, a range of lengths being rolled. The chart shown is for a billet about 33 ft. long. The total time of the cycle is 47 seconds, during which time the load is maintained for about 20 seconds. Approximately 29 seconds is required for the billet to pass through any individual stand. All stands are full for a period of about 14 seconds. The load peak is 1440 kw input, corresponding to an output of about 1810 hp, which is 90 percent of the motor rating. It will be seen that the duration of the load peak is too great to permit any appreciable advantage to be gained through the use of a flywheel. Moreover the speed regulation necessary to obtain any appreciable effect from a flywheel, would be prohibitive, due to the impossibility of maintaining correct relative speeds between the roughing stand and the stands following.

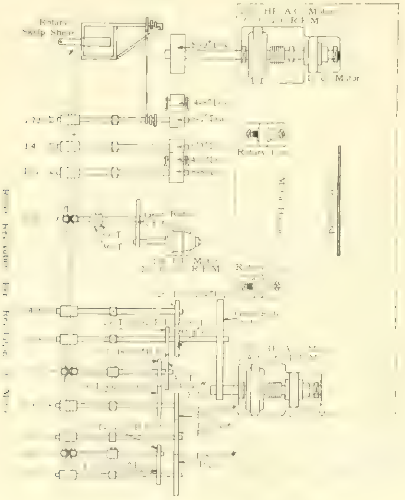

FIG. 2—PLAN OF 10 INCH SKELP MILL

The speed of the roughing mill motor during the above operation varied from 359 r.p.m. when idling to 349 r.p.m. under peak load, a slip of three percent. The power-factor is indicated by an average of readings taken while rolling several billets. These values are as follows:—

Ave. Kw Input Rolling	Ave. Primary Amperes	Primary Volts	Power-Factor
1250	400	2240	81 percent lag

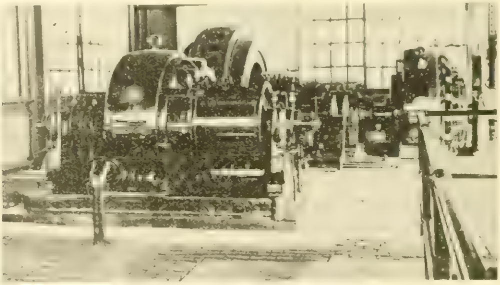
FIG. 3—THE MAIN DRIVING MOTORS

In the background is seen the 2000 hp, three-phase motor, with a 700 hp direct-current motor mounted on the same shaft. In the foreground is the rotary converter which produces adjustable speed.

The chart shown in Fig. 6 shows the load on the finishing drive when rolling from 7⅝ by 0.315 in. to 7⅝ by 0.175 in. in this mill. The motor was operated in connection with the rotary converter and auxiliary motor. The field of the direct-current motor was such as to cause an induction motor speed of 163 r.p.m. at 70 percent load. As the synchronous speed of the induction motor is 240 r.p.m., the slip was 32.5 percent, which is the maximum range of the set. The rolling load output of the rotary converter was 470 volts and 1050 amperes, giving 494 kw, which is rated capacity. The speed of the converter was 550 r.p.m., corresponding to 18.3 cycles. This checks fairly well with the observed motor speed.

The chart shown in Fig. 7 shows more in detail, the load cycle on the finishing mill motor with the above service. It will be noted that the steel enters and leaves the mill quickly, due to its high speed. During the period that the mill is full, the load is quite uniform.

The steel is in the mill a total of 28 seconds. This time is less than the corresponding time in the roughing mill, shown in Fig. 3, both because the original billet for Fig. 5 was only 28 feet long and also because of the lesser number of stands in the finishing mill. The load demand on the finishing mill, as in Fig. 5 was about 1200 kw input, or about 70 percent of the motor capacity.

The chart shown in Fig. 8 shows the loading of the roughing mill motor when rolling 2 by 2 in. billets to 2⅝ by 0.285 in., the finished product being 2⅝ by 0.108 in. The induction motor was operated with short-circuited secondary. It will be noted from this chart that the billets followed in rapid succession, keeping the mill quite full. The peak loads are about 650 kw input, about one-third rated capacity. The speed under these peaks was 355 r.p.m. or 1.4 percent slip. The power-factor is shown by the following readings:—

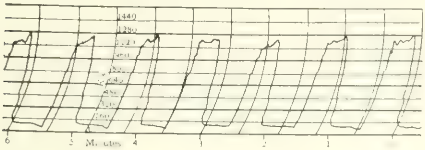

FIG. 4—LOAD CYCLE OF THE ROUGHING MILL

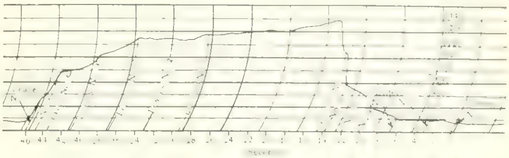

FIG. 5—DETAIL ANALYSIS OF ONE CYCLE OF ROUGHING MILL

Ave. Kw Input	Ave. Primary Amperes	Primary Volts	Power-Factor
No load—100	184	2240	14 percent lag
Rolling -650	264	2240	63.5 percent lag

The chart shown in Fig. 9 indicates the load on the finishing mill on light service, rolling 2⅝ by 0.285 in. to 2⅝ by 0.018 in. Dynamic regulation was used to obtain a motor speed of 221 r.p.m. This is a slip of 4.75 cycles or 7.9 percent. The observed speed of the rotary converter was 226 r.p.m. The direct-current load on the converter, corresponding to the rolling demand, was 110 volts, 600 amperes, or 66 kw, which is 13 percent of the converter capacity. The load on the induction motor is fairly well sustained, due to the rapid succession of billets. The load with the mill full of steel is about 800 kw input.

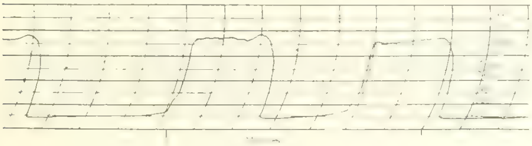

FIG. 6—LOAD CYCLE OF FINISHING MILL

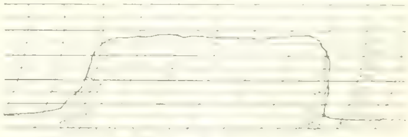

FIG. 7—DETAIL ANALYSIS OF ONE CYCLE OF FINISHING MILL

The effect upon power-factor of dynamic regulation with an over-excited rotary converter is illustrated by the following tabulation, showing the conditions with the finishing mill drive operating with the auxiliaries.

Kw Input	Percent Full Load	Power-Factor
800	48	93.5
1175	71	96.5

Fig. 10 shows how the power-factor of the finishing mill drive is increased when it is operated with the rotary converter. It will be noted that the load on the main motors is higher in rolling the heavier material. This material is rolled at the lower speed in the finishing mill. As the heavier load coincides with the lower speed, the need of a constant horse-power drive is indicated for a mill of this type.

These sets were not planned to operate above synchronism. However, it has become evident that a higher speed would be advantageous on the roughing mill, particularly in rolling the lighter orders. Plans are now under way to operate this mill drive throughout a range up to about 20 percent above synchronous speed. The motor has been taken through synchronism, pulling the friction load of the mill (100 kw) with no difficulty. It has been found satisfactory to operate with the auxiliaries up to a point four percent below synchronism. It is expected to duplicate this performance above synchronism. Operating on resistance the slip under load is about three percent. This will leave a range of seven percent of rated speed which the speed set will not cover. As it is the practice to determine the speed of the roughing mill and adapt the speeds of the other mills to correspond, this inactive range will not be a serious drawback.

Some conditions which may permit the use of adjustable speed sets to advantage, may be suggested.

a—Where a range of orders is rolled, calling for different speeds for best quantity or quality of production.

b—Where a mill runs in tandem with another mill, the speed of the second mill can be suited to the output of the first. Also the division of the work of the two mills may be varied and the speeds adjusted to suit.

c—Where it is desirable to vary the rate of production or to allow for increased production, as operators gain skill

d—To speed up an existing mill, by operating the motor above synchronism.

The rotary converter system of speed control, using the rotary converter auxiliary, is at its best in connection with 60 cycle main motors. It is then generally possible to use a standard 25 cycle rotary converter which will run from 0 to 18 cycles for 30 percent speed range. For 25 cycle installations the converter operates at low frequency and low speed and is relatively more expensive.

The relative cost of a constant speed drive, as compared with a similar adjustable speed drive, will depend materially upon local conditions. It may be said in general, however, that the auxiliary apparatus and control will add from 50 to 75 percent above the cost of the main motor. The cost of installation will be increased in a like degree.

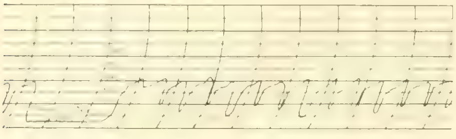
FIG. 8—LOAD CYCLE OF ROUGHING MILL WITH SMALL BILLETS

It will usually be found that the constant horsepower drive is preferable to the constant torque drive in that the heaviest load demands will occur in connection with work requiring the lower operating speeds. If a constant torque drive be then installed, having sufficient capacity to handle the low speed load demand, it will have excess capacity at the higher speed. The larger main motor required to afford this excess capacity will add to the cost. The relative cost of constant horsepower vs constant torque sets will depend upon such considerations as nature of load, speed range and speed of main motor. It may be stated that, in general, there is not a wide difference in cost between the two systems.

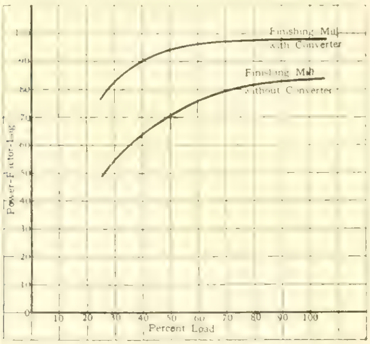

FIG. 10—EFFECT OF ROTARY CONVERTER ON POWER-FACTOR OF MAIN MOTOR

It is entirely possible to add auxiliary equipment to secure dynamic regulation upon existing simple induction motor drive. If the secondary characteristics of the motor are such that standard units may be used for auxiliaries, the proposition is feasible. In such instances the constant torque scheme will be more naturally selected as not involving structural changes in the main motor.

Dynamic regulation may be employed for operating an induction motor above synchronism as well as below synchronism, provided mechanical considerations permit. This is done by reversing the shunt field of the auxiliary motor. This reverses its voltage, which in turn reverses the direction of rotation of the rotary converter and causes its frequency to be additive with respect to the secondary frequency of the induction motor. The current flow in the direct-current circuit does not reverse. Below synchronism the auxiliary unit acts as a direct-current motor. Above synchronism it acts as a direct-current generator. As the current does not reverse, the commutating-pole polarity remains correct for the changed condition. If the unit is compound-wound, the action is cumulative below synchronism and differential above synchronism. This leads to a drooping characteristic in either case.

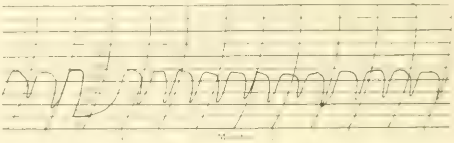
FIG. 9—LOAD CYCLE OF FINISHING MILL WITH SMALL BILLETS

With this type of drive, the set has a limited torque over a narrow speed range slightly below and above synchronism. The torque available over this range depends upon the pull-in torque of the rotary converter unit. The available torque is not less than 10 percent rated torque of the drive. This is sufficient to pull through synchronism, the average mill having a friction load of about five percent of the motor rating.

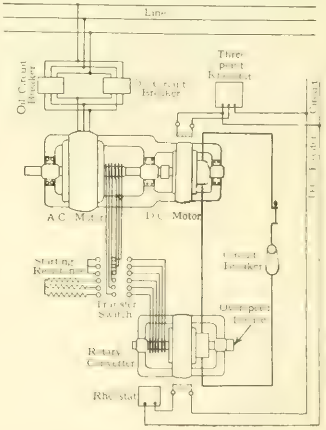

FIG. 11—SCHEMATIC DIAGRAM OF CONSTANT HORSEPOWER ADJUSTABLE SPEED EQUIPMENT

When good speed regulation is desired, the auxiliary direct-current unit is either shunt wound or supplied with a small amount of compounding. Where flywheels are utilized, heavier compounding is employed to secure the desired drooping characteristic. A constant horse-power unit requires more compounding than a constant torque unit to offset the effect of speed variation.

The range of speed control afforded by these sets is usually of the order of 30 to 35 percent, although sets have been built to give 50 percent speed reduction. The greater the range, the larger are the auxiliaries required. A wide range may be obtained by selecting a synchronous speed at an intermediate value and employing the auxiliaries to operate both above and below this speed.

In Fig. 11 is shown schematically the connection diagram of a rotary converter adjustable speed equipment. It will be seen from the diagram that this system of adjustable speed operation is extremely simple, and is accomplished by means of standard apparatus. The main alternating-current motor, the direct-current motor, the rotary converter and the control, are all well understood by mill operators, so that no specially skilled attendant or repairman is required to keep the apparatus in operation. The apparatus is so simple that only minor repairs and adjustments are necessary, thus reducing the delays on account of the apparatus to a minimum.

The Cost of Interruptions of Power to Steel Mills

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Central stations have served the iron and steel industry in a very creditable way during the war, making possible extensions to existing plants as well as new plants, which would not have been possible except for the very flexible service they maintained. This service has been particularly helpful to those plants which depend partly or entirely upon purchased power.

The central stations maintain an organization whose sole duty is the development, distribution and vending of power. On the other side of the power contract is another organization which is maintained by the purchaser for the purpose of delivering continuous service to the operating departments in the steel works. The one point of contact between these two parties is brought about through an interruption of the power service. To those not familiar with the seriousness of power interruptions in the steel industry, the following summary will be of interest.

The greatest effect of an interruption of power occurs in the continuous rod mill, where hot steel is at times in as many as 16 rolls at once and where failure of power, coming as it does without a moment's notice, allows this steel to become cold while between the rolls. After clearing the steel out of the mill by loosening the rolls and by the use of an overhead crane, it is then necessary to reset the entire mill, which includes lining up of the many guides, the rolls themselves and numerous troublesome adjustments. It is about equivalent to setting the mill for a new order. A minute's interruption means not a minute to this type of mill, but from 30 to 45 minutes. In about 60 percent of such delays the mill is caught full of steel and in the other 40 percent it is at various stages.

During the spring and fall months when long transmission lines are subject to severe storms, several delays of a few minutes each during the day will easily decrease the production from 30 to 40 percent, owing to the time necessary to clear the mill, reset and readjust the guides and rolls before normal rolling conditions can be resumed. In addition to the above there is a loss due to the steel it is necessary to scrap, because it has become solid in the mill or is off-size.

In continuous billet mills of six and eight stands, where the section of steel entering the mill averages around six inches square, power failures necessitate the same work and readjustments and scrapping of steel, but of course the labor of taking the cold metal out of the rolls is greater, owing to the increased weight of the section and heavier parts to handle.

In the case of the roughing or blooming mill, a short delay of a few minutes does not delay the mill, outside of the actual time the power is off, as an ingot can be finished, providing it has not been chilled below a rolling temperature. If it gets too cold, and has been passed through the mill several times, which increases its length, it will have to be scrapped, as it is too long to be returned to the pits for re-heating.

In sheet mills there is generally enough energy in the flywheel connected to the main drive to allow the mill men to clear the mill of all metal. The same also applies to smaller mills.

Throughout the rest of the average steel plant, short delays are not troublesome, but if the power is off for a considerable time, serious conditions arise. In the open hearth plants where there are hundreds of tons of molten steel to handle, and in the coke plant, where there are hundreds of tons of coal in the hot ovens which must be handled on time, it is necessary to protect this class of operation by current supplied from a local generating plant.

To the writer's mind a very serious aspect of delays of this nature is, in addition to the financial loss, the effect on the men in the mill. Tonnage is their daily thought, it is talked to them day in and day out, and serves as a basis on which they are paid. Naturally enough, troubles which are beyond their control and upon which, as a general rule, they can get no information, are magnified and affect their morale far greater than troubles that they can combat and overcome by their own ingenuity.

Close contact between the power companies and steel companies' operating departments by special telephone service, if necessary, can often be the means of orders being issued in time, which would save tons of steel and much wasted idle labor, waiting around to know whether the mill will operate soon or not.

The prevailing opinion, as expressed by several large operating engineers, is that time is lost in getting in touch with the power company. If a service is maintained whereby the chief operator at the steel plant can get into immediate communication with the chief operator of the power company, part of the dissatisfaction now existing would be overcome. Of course, upon power failure the power company employees are keen in their interest to obtain normal service again and probably feel that this is their first duty, which is granted, but at the same time they should be conversant with the conditions existing on the dead end of their line.

When a transmission line is serving industries in which the process used demands a continuous supply of electric power, very serious consideration should be given to the latest developments in automatic switching by the use of section relays and duplicate supply lines so that, in case of trouble at any given point, the lines so affected will clear themselves and power will be supplied through the other side of the loop. The overcoming of troubles on transmission lines is undoubtedly, like the electrical industry itself, in its infancy, and we have yet to find that approach to utopian conditions which we desire.

Steel works in general have a great deal of waste heat which is available for the generation of power and, of course, must be developed for economical reasons. As a rule, the mill of today needs more power than is available from this source and either has to purchase power or install additional generating equipment.

A recent expression from engineers in charge of a number of these plants indicates that they would prefer to purchase their power from central stations, if reliable service could be obtained. The experience of these men indicates that some of the central stations have apparently not given the question of continuous service the thought it should have received, as the conditions of transmission, and particularly the load carried on their station, resulted in dissatisfaction.

Central stations have grown in their average capacity at a very rapid rate, as has likewise the capacity of the average steel mill power house. Fifteen years ago the average size of turbogenerators installed in a steel mill plant was 500 kw, and the maximum rating was 1000 kw, but today the average rating of turbines installed by the iron and steel industries is 3000 kw, and there are several installations where 20 000 kw units are in operation.

With the installation of such large units, economies are such that power can be generated at a very low figure, as the heat is derived from coke oven gas, blast furnace gas or waste heat boilers in connection with open hearth furnaces and heating furnaces. This condition pertains to the larger plants, leaving a very large field among the smaller plants which could be taken care of by central stations.

To this end, the writer wishes to present to the central station managements a phase of the subject with which they are not wholly conversant, that is, the financial cost of a delay.

TABLE I—COST OF ONE HOUR DELAY TO BLOOM, BILLET AND ROD MILLS

Item	Charge for	Bloom Mill	Billet Mill	Rod and Bar Mill	Total	Per-cent
1	Wages, fuel, water and other fixed charges	$ 90.00	$ 20.00	$ 66.00	$176.00	17.6
		2 tons	2 tons	¾ ton		
2	Conversion loss ..	100.00	100.00	37.00	237.00	23.7
3	Administration and selling charges ..	.....	.....	56.00	56.00	5.6
4	Interest on investment and working capital; also depreciation	32.50	11.50	25.00	69.00	6.9
5	Profit (see text)..	.....	.....	461.00	461.00	46.2
	Total				$999.00	100

To illustrate the financial cost of delays to a steel company, let us take as a unit the case of a 34 inch electric reversing blooming mill supplying steel to an 18 inch six stand continuous billet mill, which in turn supplies part of its product to a 16 stand continuous rod mill. In this case the bloom mill delivers 100 percent steel; on the average 27 percent is used for heavy bars and 73 percent blooms for the billet mill, which delivers 63 percent of its product for rods and 37 percent for small bars. Table I is based on one hour's delay to each of the above three mills. Item *1* includes wages, fuel, water, maintenance of building, general works expense, steam, water, lighting and switching charges. Item *5* is based on an estimated profit per ton of $10 for bars, $15 for rods sold and $20 for rods used in finished products.

It is hoped that these figures will help to present to the managements of central stations supplying steel mills with power a general idea of the seriousness of even momentary power interruptions and in a small way form a basis for the plea, "Help us if you can".

The Electric Furnace as a Central Station Load

With Particular Reference to Phase-Balancing Systems

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ONE of the fundamental problems in the development of the electric furnace has been that of producing installations of such electrical characteristics as to obtain power at the lowest cost. The development of the large central station, with its cheap production of power, has caused the electric furnace to become a central station load. Hence, the problem has become that of modifying the furnace load so as to obtain the best rates for power from the central station.

FACTORS AFFECTING THE COST OF POWER

The characteristics of a load which affect the cost of power, are;—the amount of power delivered, the power-factor of the load, the maximum demand, and the amount of unbalanced power. For determining the cost of supplying power for any particular load, a balanced load of unity power-factor and of constant value equal to the average load may be used as a reference load. The investments required to meet the other characteristics of the load, such as low power-factor, high short time demand and unbalanced load are taken care of by means of power-factor, demand factor and unbalance factor or a combination of these factors. The amount of power determines the capacity of the prime mover and approximately the amount of coal consumed. Low power-factor of a load increases the capacity required in generating and transmission apparatus, and also increases the investment required to obtain good regulation. Unbalanced power increases the heating in generators and increases the cost of generating and distributing apparatus, and requires additional investment to secure good regulation on the different phases of the distribution system. High demand factor requires additional capacity in all apparatus, and of course, the demand is considered with respect to the other loads on the system.

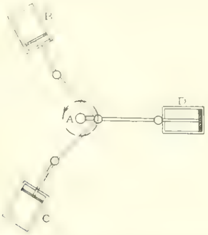

FIG. 1—MECHANICAL ANALOGY OF THREE-PHASE POWER

Before going further, it is desirable to explain more definitely just what is meant by balanced power. When the voltages of a three-phase system are equal in magnitude and displaced by 120 degrees, balanced voltages are obtained. Similarly, when the currents are equal in magnitude and displaced by 120 degrees, balanced currents are obtained. A balanced load is one of such characteristics that when balanced voltages are applied, balanced currents will flow. Balanced power is obtained when balanced voltages are applied to balanced loads. When balanced power is obtained, the flow of power is such that the total power is constant, and is not pulsating in value during the different parts of the cycle. The power in any single-phase circuit is pulsating. The power in a balanced polyphase circuit is always continuous, though the power in the different phases is pulsating.

MECHANICAL ANALOGY OF POWER FLOW

A picture of the conditions of power flow can be obtained on the basis of a mechanical analogy. Assume a motor represented in Fig. 1 to have a shaft *A* through which power is supplied to operate three cylinders, *B*, *C* and *D*, which require power for compression in either direction. Let the curve *X* in Fig. 2 represent the power required by one cylinder *B*, which corresponds to one phase of the motor. It will be observed that the power is pulsating, varying from zero to a maximum and back to zero at a frequency of twice that of the rotation of the shaft *A*. Similarly, let the curve *Y* and *Z* represent the power required by the phases *C* and *D* respectively. The total power required is the sum of the power demands for each phase, and graphically is the sum of the three curves, *X*, *Y* and *Z*. The condition of low power-factor may be represented by having power returned to the motor during part of the cycle. Graphically, this may be represented by using the line *J-K* as reference. Under this condition, negative power is power that is momentarily fed back into the system. This condition is obtained electrically, when reactors or condensers discharge the energy stored in them. It is evident from this mechanical analogy that low power-factor increases the cost of apparatus for supplying a definite amount of power. A similar arrangement of cylinders may represent a three-phase generator which receives power from its cylinders and delivers power through the shaft to the motor load. This mechanical

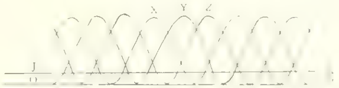

FIG. 2—CURVES OF POWER PULSATIONS

analogy now represents a three-phase load, generator and transmission system.

The curves X, Y and Z of power demand are sine curves, so as to represent the electrical conditions for the flow of power. The total power is the sum of the power demands of the different phases. Graphically, this sum is a straight line when the curves of power demand are equal in magnitude and displaced 120 degrees. Under this condition, the total power delivered by the transmission system is constant. This condition represents the operation with balanced power. It should be noted that all apparatus is operating in the most economical manner.

If the total load were of such a nature, that the loads on the different phases were unequal in magnitude, and had their maximum demands at unequal intervals, it is evident that the total load would contain pulsating power. With this kind of a load, it would be possible to shift the positions of the cylinders so as to cause the maximum demands for the different phases to occur at proper intervals, and thus obtain balanced power. This method of balancing power is accomplished, electrically, by means of "static balancers", which consist of transformers with special connections that will be described later.

If the loads on the different phases are unequal, it is evident that unbalanced power is obtained. Under this condition, the ratio of maximum to average stress is greater for delivering a given amount of power than would be the case if the total load contained no pulsating power, and hence all apparatus is operated in an uneconomical manner. Furthermore, an excessive load on one phase of the motor would tend to slow down the generator and thus disturb the loads on the other phases. If this combination of motor and generator were operated mechanically with an unbalanced load, the shaft would be provided with a flywheel. The same argument, which requires a mechanical system to be equipped with balancers in the form of flywheels or balancing weights in case of pulsating power, also applies to the electrical system. Electrical balancers should be installed where the total power taken by the load is pulsating. The electrical equivalent of the flywheel is the rotating phase balancer which draws power from one phase, and supplies it to another. The required capacity of the balancer is proportional to the amount of pulsating or unbalanced power. The static balancer requires a separate adjustment of phase position for each type of unbalanced load, whereas the rotating balancer will correct for any type of unbalance within its capacity.

This mechanical analogy shows quite clearly some of the characteristics of unbalanced power, but it should be borne in mind that all analogies are imperfect.

Having described the nature of the various factors which enter into the cost of power, the next point is to consider how these factors have affected the characteristics of the electrical apparatus in the furnace installation. The cost of power has been reduced by perfecting furnaces in the larger sizes so that the rates may be based on larger blocks of power. The furnace has been improved by reduction of thermal losses and more efficient application of the heat so that the actual amount of power, per unit of product, has been reduced. The power-factor of the furnace has been improved by elimination of the older types of induction furnaces, as well as other types which required an excessive amount of reactance in the circuit. Better interlacing of the furnace leads has brought about the condition in the arc furnaces where the amount of reactance in the circuit is only sufficient to maintain the arc. The adoption of the automatic regulator has improved the power-factor indirectly by making unnecessary the use of reactors which were installed to prevent excessive surges of power. In a few installations, unity power-factor has been obtained by the use of synchronous apparatus, consisting chiefly of motor generator sets, supplying power for single-phase furnaces or furnaces of special frequencies. The demand factor of the electric furnace load has been improved to some extent by modifying the design of the furnace so as to obtain greater stability of the arc and to a much larger extent by the use of automatic regulators. The remaining factor affecting the cost of power is the amount of unbalanced power, and considerable progress has been made in balancing the electric furnace load. As very little has been published on the operation of electric furnaces with respect to balanced power, this question will be discussed more fully.

ELECTRIC FURNACES WITH RESPECT TO BALANCED POWER

Most of the early types of electric furnaces were of small capacity and designed for single-phase operation, but in recent years the number and capacity of the furnaces have increased to such an extent that the central stations have demanded that the larger installations draw balanced power from their lines. This important restriction on the part of the central stations has caused the engineers to modify the furnace loads and to produce many new furnace systems. In practically all of the recently proposed furnace systems, some provision has been made to secure balanced power.

The requirements for obtaining balanced power, can be met by operating the furnace in the following ways:—

1—Single or polyphase furnaces with motor generator sets.

2—Single-phase furnaces simultaneously.

3—Polyphase furnaces with equal impedance between electrodes.

4—Polyphase furnaces with unequal impedances between electrodes with static balancing systems. Either special transformer arrangements or furnaces of special proportions may be employed.

5—Single or polyphase furnaces with phase balancers.

The first method, Fig. 3, involving the use of motor generator sets, is the oldest and most obvious arrangement of satisfying the requirements of balanced power. Other advantages of this arrangement are the operation of the motor at unity power-factor, the choice of generator frequency and the control of furnace voltage. The objections to this arrangement are the higher initial cost and the higher operating cost of the motor generator set due to higher maintenance, lower efficiency and the necessity for attendants.

In the second method, Fig. 4, single-phase furnaces are operated as a group, so as to draw balanced power from the supply lines. Arc or resistance furnaces may be used, and when the furnaces are similar electrically, balanced power is easily secured. The objections to this arrangement are that three single-phase furnaces are more expensive, of lower thermal efficiency and occupy more space than one polyphase furnace of the same capacity. Further objection exists in the fact that these furnaces are usually charged at different times, and in other ways are not operated as a group, and under these conditions, the load is not even approximately balanced.

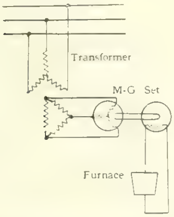

FIG. 3—A SINGLE-PHASE LOAD BALANCED BY A MOTOR GENERATOR SET

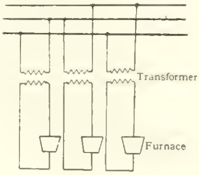

FIG. 4—THREE SINGLE-PHASE LOADS BALANCED ON A THREE-PHASE SYSTEM

The third method, Fig. 5, is the most common, and involves the symmetrical placing of the electrodes in the top of the furnace. The furnaces are provided with electrode hoisting mechanisms which are operated preferably by automatic control, in order to maintain equal current and therefore equal impedance in each phase of the furnace. As the furnace load is of the same impedance between phases, the load is normally a balanced load and any standard polyphase transformer system may be used to step down to furnace voltage. The conditions for balanced power are that the impedances of the different phases be equal and of the same power-factor, not only in the furnace itself, but also in the furnace leads and in the power transformers. These conditions are easy to obtain, due to the symmetry of the arrangement. In this connection it may be pointed out that installations have been made with an unsymmetrical arrangement of furnace leads which caused the voltages at the electrodes to be considerably unbalanced. This unbalanced voltage caused unequal heating under the different electrodes and caused the total power drawn from the supply to be unbalanced.

Some of the standard transformer connections have a neutral point in the secondary, and this neutral point may be connected to the furnace hearth. It should be noted, however, that this connection, though providing a path for the harmonic and rectified currents, does not permit any current of normal frequency to flow through the hearth when balanced power is secured.

The fourth method can be considered as a modification of the third method, for metallurgical reasons. From the beginning of the electric furnace development, many operators have maintained that it is desirable to have bottom electrodes for compelling the current to flow through the material being treated, so that part of the heat is generated in the bath and in the electrodes below. Further advantage exists in the reduction of the number of movable carbon or graphite electrodes. Hence many ingenious arrangements have been proposed, particularly for steel furnaces, to provide a furnace with bottom electrodes in combination with a transformer system that will meet the requirements of drawing balanced power from the supply lines.

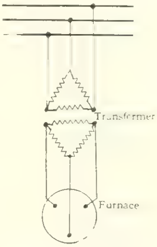

FIG. 5—SYMMETRICAL THREE-PHASE FURNACE LOAD

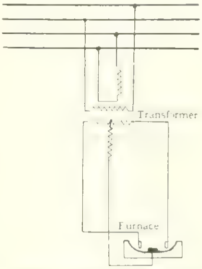

FIG. 6—UNBALANCED LOAD WITH SCOTT CONNECTION

In the usual case, two top and one bottom electrodes are used. The impedance of the furnace between the two top electrodes, having two arcs in series is obviously different from the impedance between a top and bottom electrode, having one arc, the bath and conducting hearth in series. This arrangement may be represented as a solid to which power is supplied from three points. This complex network can be replaced by three impedances of different values connected in delta; and this can be further simplified by assuming that the impedances between the top and bottom electrodes are equal. The furnace load might also be represented by three impedances connected in star. In this case it is evident that the impedance of each phase of the furnace leads may be added to the impedance of the corresponding phase of the furnace and these values used to represent the total furnace load.

It is evident that unbalanced power is produced if an equilateral triangle of voltage is impressed on this type of furnace. To reduce this unbalanced power, the transformer system must be such as to permit a variation in the shape of the triangle of voltage impressed upon the furnace, and this can be done by using transformers of different ratios. The change in shape of the furnace voltage triangle also changes the phase of the furnace currents from being displaced 120 degrees from each other. The transformer system must also provide a means of combining these currents so as to produce primary line currents displaced 120 degrees from each other.

Some of the standard transformer connections can be modified to meet the requirements for balanced power and others cannot. With this type of furnace the only transformer connections which satisfy the requirements for balanced power are:—

Scott Connection—Fig. 6.
Star-delta —Fig. 7.
Delta-star —Fig. 8.

The calculations, included in the appendix, show that it is possible to secure balanced power from a furnace having two top and one bottom electrodes by the use of star-delta, delta-star or Scott connected transformers of suitable ratio, providing that the furnace impedances are of the same power factor. The Scott connected transformers are suitable for two-phase supply and the star-delta or delta-star are suitable for three-phase supply. Between the last two connections there is little choice except as to cost. The transformers of the star-delta system are designed for higher secondary voltage, (line voltage instead of star voltage) and lower secondary current, (delta current instead of line current) and, therefore, are cheaper than transformers of the corresponding delta-star system. If the ratio of the furnace impedances changes during the heat, it may be necessary to change the transformer ratios so as to maintain balanced power.

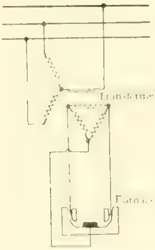

FIG. 7—UNBALANCED LOAD WITH STAR-DELTA CONNECTION

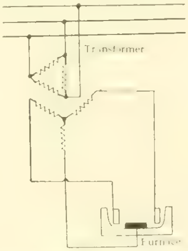

FIG. 8—UNBALANCED LOAD WITH DELTA-STAR CONNECTION

Other transformer systems have been used to reduce the amount of unbalanced power, which do not satisfy the conditions for obtaining balanced power. For example, with the Tee-connection, Fig. 9, the only condition for obtaining balanced power is that the impedances between the different electrodes be equal. This condition cannot be satisfied with a furnace having two top and one bottom electrodes. Another connection sometimes used is the two-phase, three-wire system, Fig. 10. With this connection the condition for obtaining balanced power is that the impedances between the two upper electrodes be infinite. This condition cannot be satisfied with a furnace having two top and one bottom electrodes. In case the three electrodes are placed in the top of the furnace, it is also impossible to secure balanced power.

The attempt has frequently been made to obtain balanced power by using some transformer arrangement which gives equal transformer currents, such as the one shown in Fig. 11. It is obvious that since the load is single-phase and therefore pulsating, the power drawn from the supply is also pulsating or unbalanced.

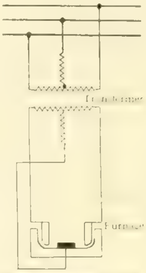

FIG. 9—UNBALANCED LOAD WITH TEE CONNECTION

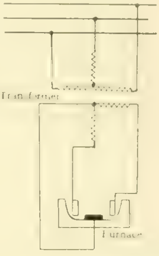

FIG. 10—UNBALANCED LOAD WITH TWO-PHASE, THREE-WIRE CONNECTION

There is, however, a special connection* shown in Fig. 12, by means of which a single-phase load may be balanced by the addition of a reactor. The explanation may be readily shown by a vector diagram, Fig. 13. E_a and E_b are the voltages, I_a and I_b are the currents due to the resistance furnace load. The primary currents are equal in magnitude, but are not displaced 90 degrees in phase. The proper phase displacement may be obtained by adding the reactor current, I_x to I_a so as to obtain the current I'_a, which is equal to and displaced 90 degrees from I_b. By this means balanced power is obtained at 70 percent power-factor. Hence, this is not a good balancing scheme, but it illustrates static balancing systems.

To avoid the special transformer connection required by the preceding method, furnaces have been built with two top and two bottom electrodes supplied from a two-phase, four-wire system, Fig. 14. The usual carbon cylinders form the top electrodes and steel grids imbedded in high resistance refractory ma-

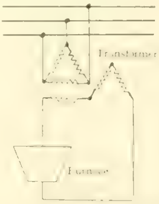

FIG. 11—EQUAL TRANSFORMER CURRENTS FROM SINGLE-PHASE LOAD

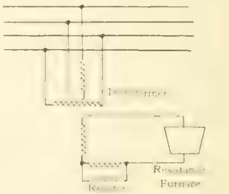

FIG. 12—SINGLE-PHASE LOAD BALANCED BY MEANS OF AN ADDITIONAL REACTOR

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*See "The Supply of Single-Phase Power from Three-Phase Systems" by Miles Walker, *Inst. Elec. Engrs.*, Vol. 57, pp. 100-130 terial form the bottom electrodes. The furnace load may be represented as a solid to which power is supplied at four points from a two-phase system. This complex network can be replaced by an equivalent network of six impedances. The solution of this network can be obtained by setting up the equations according to Kirchhoff's laws and solving by determinants. The solution which is given in the appendix shows that balanced power can be secured when the furnace impedances bear a certain definite relation one to another. If the ratios of the furnace impedances change during the heat, it is possible that the length of the arc may be varied so as still to satisfy the conditions for balanced power.

The fifth method, involving the use of phase balancers, has been proposed at many stages of the development of electric furnaces. In the past this scheme, involving as it does the use of rotating machinery, has been considered rather expensive for commercial installations. Within the last few years, the knowledge of phase converters has been greatly increased and an inherently self-balancing phase converter has been produced.** When the phase converter involves a synchronous machine, there is the further possibility of using the machine as a condenser, so as to make the furnace load of approximately unity power-factor. One method of using these possibilities to advantage with electric furnaces is shown in Fig. 15. In this case the phase converter is similar to a synchronous condenser, except for the special damper windings. An auxiliary machine of the induction motor type is connected in series with the main converter, and is driven from the converter shaft. In this arrangement, the phase converter carries its maximum load as a synchronous condenser and zero load as a converter when the three furnaces are operating at full load. The phase converter carries its greatest load as a converter and its smallest load as a condenser when only one furnace is operating. On this account, the capacity of the phase converter is determined by its operation as a synchronous condenser for furnace loads of 85 to 90 percent power-factor or below. It is possible to secure the advantages of phase balancing by using a synchronous condenser provided with additional damper windings on the rotor, and a small induction motor mounted on the shaft of the condenser. The size of the phase converter depends upon the amount of unbalanced load and not on the total amount of load. For balancing single-phase loads the capacity required of the phase converter is approximately half of that required of either unit of the corresponding motor-generator set. The size of the auxiliary machine depends upon the impedance of the phase converter. It usually would be from ten to twenty percent of the capacity of the converter. Recently some operators have insisted upon apparatus for correcting the power-factor of the furnace loads. Thus the combination of phase balancing and power-factor correction in one unit make this scheme a promising one.

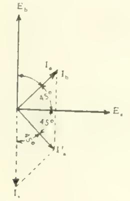

FIG. 13—VECTOR DIAGRAM OF CONNECTIONS SHOWN IN FIG. 12

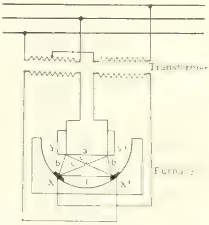

FIG. 14—BALANCED TWO-PHASE LOAD

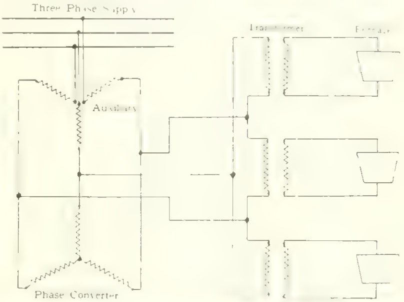

FIG. 15—APPLICATION OF PHASE CONVERTER TO FURNACE CIRCUITS

CONCLUSION

There are several methods available which enable the electric furnace to draw balanced power from the supply lines. Methods of determining the unbalance of a load are available.† The present trend of development indicates that in the future more attention will be paid to methods of balancing furnace loads and to determining the cost of supplying unbalanced loads.

APPENDIX

MODIFIED SCOTT CONNECTION

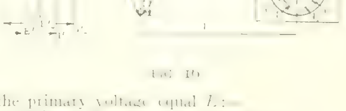
FIG. 16

Let the primary voltage equal E:—

$a_1 = E_1 \div E'_w$ for main transformer.

$a_2 = E_2 \div E'_z$ for teaser transformer.

y_1 = Admittance between top electrodes.

y_2 = Admittance between top and bottom electrodes.

Assume primary voltages:—

$E'_w = E$

$E'_z = -jE$

**See paper by C. L. Fortescue on "Method of Symmetrical Co-ordinates Applied to the Solution of Polyphase Networks," *A. I. E. E. Proc.*, June 1918, p. 702.

†See paper on "Measurement of Power-Factor on Unbalanced Polyphase Circuits," presented by the writer at the 1920 Summer Convention of the A. I. E. E.

Secondary or furnace voltages:—

$E_1 = -a_1 E$
$E_2 = \frac{1}{2} a_1 E - ja_2 E$
$E_3 = \frac{1}{2} a_1 E + ja_2 E$

Furnace delta currents:—

$I_1 = -a_1 Ey_1$
$I_2 = \frac{1}{2} a_1 Ey_2 - ja_2 Ey_2$
$I_3 = \frac{1}{2} a_1 Ey_2 + ja_2 Ey_2$

The secondary currents are:

$I_y = I_1 - I_3 = -a_1y_1E - \frac{1}{2} a_1y_2E - ja_2y_2E.$
$I_x = I_2 - I_1 = +a_1y_1E + \frac{1}{2} a_1y_2E - ja_2y_2E.$
$I_z = I_3 - I_2 = +j\,2a_2y_2E.$

The currents, I_x and I_y, each flow through one-half of the total low-voltage windings on a common core and they can be replaced by an equivalent current I_w flowing through the total winding.

$I_w = -a_1y_1E - \frac{1}{2} a_1y_2E.$

The primary currents are:

$I'_w = a_1^2y_1E + \frac{1}{2} a_1^2y_2E.$
$I'_z = -j\,2\,a_2^2\,y_2E.$

On substituting the condition that the currents be equal in magnitude, the following equation is secured:

$2\,a_2^2\,y_2E = a_1^2\,y_1E + \frac{1}{2}\,a_1^2\,y_2E.$

$$\frac{y_2}{y_1} = \frac{2\,a_1^2}{4\,a_2^2 - a_1^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (A)$$

When the transformer ratios and the furnace admittances are such as to satisfy equation (A), the condition for balanced power has been obtained. The primary voltages were assumed equal in magnitude and displaced 90 degrees in phase, and the resulting currents are equal in magnitude and are displaced 90 degrees in phase.

It is interesting to substitute the condition that the furnace impedances are equal, that is, $y_1 = y_2$ into equation (A), which gives the ratio $a_2 \div a_1 = 0.866$ which checks the well known ratio of Scott-connected transformers for two-phase to three-phase transformation.

Further examination of equation (A) shows that balanced power can only be secured when the furnace impedances are of the same power-factor. The right hand member of this equation involves only real numbers and hence the left hand member must also involve only real numbers, and this condition is secured only when the impedances are of the same power-factor. Hence, it is possible to secure balanced power from a furnace having two top and one bottom electrodes by the use of Scott-connected transformers of suitable ratios, providing the furnace impedances are of the same power-factor.

STAR-DETLA CONNECTION

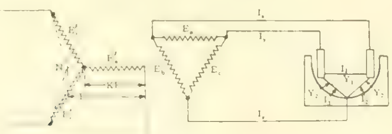

FIG. 17

Let $\sqrt{3}\,E$ = absolute value of three-phase supply voltage.

$a_1 = E_a \div E'_a$
$a_2 = E_b \div E'_b = E_c \div E'_c$
$k = E'_a \div E$
y_1 = admittance between top electrodes.
y_2 = admittance between top and bottom electrodes.

Assume the primary star voltages as:

$E'_a = kE$
$E'_b = -1.5\,E + kE + j\,.866\,E$
$E'_c = -1.5\,E + kE - j\,.866\,E$

Then the secondary or furnace voltages are:

$E_a = -ka_1\,E$
$E_b = +1.5\,a_2E - ka_2E - j\,0.866\,a_2E$
$E_c = +1.5\,a_2E - ka_2E + j\,0.866\,a_2E$

The furnace delta currents are:

$I_1 = -ka_1y_1E$
$I_2 = +1.5\,a_2y_2E - ka_2y_2E + j\,0.866\,a_2y_2E$
$I_3 = +1.5\,a_2y_2E - ka_2y_2E - j\,0.866\,a_2y_2E$

The currents in the furnace leads are:

$I_x = I_1 - I_3 = -ka_1y_1E - 1.5\,a_2y_2E + ka_2y_2E + j\,0.866\,a_2y_2E$
$I_y = I_2 - I_1 = +ka_1y_1E + 1.5\,a_2y_2E - ka_2y_2E + j\,0.866\,a_2y_2E$
$I_z = I_3 - I_2 = -j\,1.732\,a_2y_2E$

The currents flowing in the delta of the transformer group are such as to produce the currents I_x, I_y, I_z flowing in the furnace leads.

Hence the following equations determine the value of the delta currents:

$I_c - I_a = I_y$
$I_b - I_c = I_z$
$a_1I_a + a_2I_b + a_2I_c = 0$

This last equation follows from the fact that the sum of the currents flowing into the star point on the primary winding must equal zero. The solution of the above equations by determinants is as follows:

$$I_a = -\frac{a_2\,(2\,I_y + I_z)}{2\,a_2 + a_1}$$

$$I_b = +\frac{a_2I_z + a_1\,I_y + a_2I_z}{2\,a_2 + a_1}$$

$$I_c = +\frac{a_1I_y - a_2I_z}{2\,a_2 + a_1}$$

The transformer secondary currents are:

$(2\,a_2 + a_1)\,I_a = -2\,ka_1a_2y_1E - 3\,a_2^2y_2E + 2\,ka_2^2y_2E$
$(2\,a_2 + a_1)\,I_b = +ka_1^2y_1E + 1.5\,a_1a_2y_2E - ka_1a_2y_2E$
$\qquad - j\,(0.866\,a_1a_2y_2 + 1.732\,a_2^2y_2)\,E$
$(2\,a_2 + a_1)\,I_c = +ka_1^2y_1E + 1.5\,a_1a_2y_2E - ka_1a_2y_2E$
$\qquad + j\,(0.866\,a_1a_2y_2 + 1.732\,a_2^2y_2)\,E$

The line currents on the high-voltage side are:

$(2\,a_2 + a_1)\,I_a' = +2\,ka_1^2a_2y_1E + 3\,a_2^2a_1y_2E - 2\,ka_2^2a_1y_2E$
$(2\,a_2 + a_1)\,I_b' = -ka_1^2a_2y_1E - 1.5\,a_2^2a_1y_2E + ka_2^2a_1y_2E$
$\qquad + j\,(0.866\,a_2^2a_1y_2E + 1.732\,a_2^3y_2E)$
$(2\,a_2 + a_1)\,I_c' = -ka_1^2a_2y_1E - 1.5\,a_2^2a_1y_2E + ka_2^2a_1y_2E$
$\qquad - j\,(0.866\,a_1a_2^2y_2E + 1.732\,a_2^3y_2E)$

It is evident that the sum of the primary currents is zero. The conditions for balanced power are,—

(1) That ½ the real part of I_a' would be equal to the real part of I_b' and I_c', and it is evident that this is true.

(2) That 0.866 of the real part of I_a' be equal to the imaginary parts of I_b' and I_c' and that their signs should be different.

The second condition gives the following relation:—

$$\frac{y_1}{y_2} = \frac{a_2^2 + ka_1\,a_2 - a_1a_2}{ka_1^2}$$

The condition for the sum of the secondary voltages to equal zero determines the value of k, which is

$$k = \frac{3\,a_2}{a_1 + 2a_2}$$

On substituting this value of k into the previous equation, the following equation is secured:—

$$\frac{y_1}{y_2} = \frac{2\,a_2^2 + 2\,a_1\,a_2 - a_1^2}{3\,a_1^2}$$

Hence it is possible to secure balanced power with a furnace having two top and one bottom electrodes by the use of a star delta connection of transformers when the star point on the primary is properly displaced and when suitable transformer ratios are employed, providing that the furnace impedances are of the same power-factor.

DELTA-STAR CONNECTION

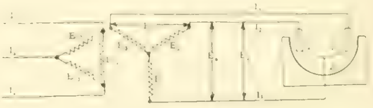

FIG. 18

Let E = absolute value of three-phase supply voltage.

$a_1 = E_1 \div E_1'$
$a_2 = E_2 \div E_2' = E_3 \div E_3'$
z_1 = impedance between bottom electrode and the neutral point of the bath.
z_2 = impedance between top electrode and the neutral point of the bath.

Let the primary voltages be:

$E'_1 = \qquad + j\,E$
$E'_2 = -0.866\,E - j\,0.5\,E$
$E'_3 = +0.866\,E - j\,0.5\,E$

The secondary star voltages are:

$$E_1 = \qquad - ja_1E$$
$$E_2 = + 0.866\ a_2E + j\ 0.5\ a_2E$$
$$E_3 = - 0.866\ a_2E + j\ 0.5\ a_2E$$

The furnace voltages are:

$$E_a = 0.866\ a_2E + j\ (0.5\ a_2 + a_1)\ E$$
$$E_b = 0.866\ a_2E - j\ (0.5\ a_2 + a_1)\ E$$
$$E_c = - 1.732\ a_2E$$

The currents flowing in the furnace are such as to produce drops equal to the impressed voltages, and in addition the sum of these currents must be zero. The conditions are sufficient to determine the value of the furnace currents by the solution of the following equations:—

$$I_1z_1 - I_2z_2 = - E_a$$
$$I_2z_2 - I_3z_2 = - E_c$$
$$I_1 + I_2 + I_3 = 0$$

The solution of the above equations by determinants is as follows:—

$$I_1 = - \frac{2z_2E_a + z_2E_c}{2z_1z_2 + z_2^2}$$
$$I_2 = - \frac{z_1E_c - z_2E_a}{2z_1z_2 + z_2^2}$$
$$I_3 = + \frac{z_2E_c + z_1E_c + z_2E_a}{2z_1z_2 + z_2^2}$$

The transformer secondary or furnace currents can now be written:—

$$(2\,z_1z_2 + z_2^2)\ I_1 = - j\ (a_2z_2 + 2\ a_1z_2)\ E$$
$$(2\,z_1z_2 + z_2^2) I_2 = + 1.732\ a_2z_1E + 0.866 a_2z_2E + j\,(0.5\ a_2z_2 + a_1z_2)\ E$$
$$(2\,z_1z_2 + z_2^2)\ I_3 = - 1.732 a_2z_1E - 0.866 a_2z_2E + j\,(0.5\ a_2z_2 + a_1z_2)\ E$$

The transformer primary currents are:

$$(2\,z_1z_2 + z_2^2)\ I'_1 = + j\ (a_1a_2z_2 + 2\ a_1^2z_2)\ E$$
$$(2\,z_1z_2 + z_2^2)\ I'_2 = - 1.732\ a_2^2z_1E - 0.866\ a_2^2z_2E - j\ (0.5\ a_2^2z_2 + a_1a_2z_2)\ E$$
$$(2\,z_1z_2 + z_2^2)\ I'_3 = + 1.732\ a_2^2z_1E + 0.866\ a_2^2z_2E - j\ (0.5\ a_2^2z_2 + a_1a_2z_2)\ E$$

The line currents on the high-voltage side are:

$$(2\,z_1z_2 + z_2^2)\ I_x = + 1.732\ a_2^2z_1E + 0.866\ a_2^2z_2E - j\ (2\ a_1a_2z_2 + 0.5\ a_2^2z_2 + 2\ a_1^2z_2)\ E$$
$$(2\,z_1z_2 + z_2^2)\ I_y = + 1.732\ a_2^2z_1E + 0.866\ a_2^2z_2E + j\ (2\ a_1a_2z_2 + 0.5\ a_2^2z_2 + 2\ a_1^2z_2)\ E$$
$$(2\,z_1z_2 + z_2^2)\ I_z = - 3.464\ a_2^2z_1E - 1.732\ a_2^2z_2E$$

The conditions for balanced power are that the line currents be equal in magnitude and displaced 120 degrees from each other. An examination of the above equations show that these conditions may be simplified into the following:—(1) that ½ the real part of I_z must equal the real part of I_x and I_y; (2) that 0.866 of the real part of I_z must equal the imaginary part of I_x and I_y and that their signs be different. The second condition gives the following equations:—

$$3\ a_2^2z_1 + 1.5\ a_2^2z_2 = 2\ a_1a_2z_2 + 0.5\ a_2^2z_2 + 2\ a_1^2z_2$$
$$\frac{z_1}{z_2} = \frac{2\ a_1^2 + 2\ a_1a_2 - a_2^2}{3\ a_2^2}$$

The above equation shows that balanced power can be secured from this type of furnace by using transformers of suitable ratios, provided the loads in the secondary circuit have the same power-factor.

FURNACES WITH TWO TOP ELECTRODES AND TWO BOTTOM ELECTRODES

In this furnace, Fig. 14, y and y' represent two top electrodes, x and x' represent two iron grids embedded in high resistance refractory material. The condition in the furnace may be represented as a solid to which power is supplied from four points and this solid may be replaced by an equivalent net work of six impedances, as shown in Fig. 19.

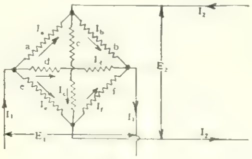

FIG. 19

Let E = absolute value of the two-phase supply voltage. Assume the impedances and currents with positive directions as indicated. By setting up the equations according to Kirchhoff's laws and letting $E_1 = E$ and $E_2 = + jE$, the following equations are secured:

$$I_1 = I_a + I_d + I_e$$
$$= I_b + I_d + I_f$$
$$I_2 = - I_a + I_b + I$$
$$aI_a + bI_b = E$$
$$eI_e + fI_f = E$$
$$bI_b - fI_f = + jE$$
$$cI_c = + jE$$
$$dI_d = E$$
$$I_1 = - jI_2$$

The last of the above equations represents the conditions that must be obtained in the furnace in order to secure balanced power.

The solution of the foregoing equations to obtain the condition for balanced power is secured by setting the following determinant equal to zero:—

$$\begin{array}{ccccccccc} I_a & I_b & I & I_d & I_e & I_f & I_1 & I_2 & K \\ \hline 1 & 0 & 0 & 1 & 1 & 0 & -1 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 & 1 & -1 & 0 & 0 \\ -1 & 1 & 1 & 0 & 0 & 0 & 0 & -1 & 0 \\ a & b & 0 & 0 & 0 & 0 & 0 & 0 & E \\ 0 & 0 & 0 & 0 & e & f & 0 & 0 & E \\ 0 & b & 0 & 0 & 0 & -f & 0 & 0 & +jE \\ 0 & 0 & c & 0 & 0 & 0 & 0 & 0 & +jE \\ 0 & 0 & 0 & d & 0 & 0 & 0 & 0 & E \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & +j & 0 \end{array} = 0$$

The solution of the above determinant gives the following general expression:

$$\frac{2f}{eb} - \frac{2}{a} + jf\left(\frac{1}{ac} - \frac{1}{ad} + \frac{1}{ae} + \frac{1}{ce} - \frac{1}{cd}\ \frac{1}{\text{[illegible]}} - \frac{1}{\text{[illegible]}} - \frac{1}{bf}\right)$$
$$+ j\left(\frac{1}{b} + \frac{1}{c} - \frac{1}{d} - \frac{1}{e}\right) = 0$$

The above is the general solution for this type of net work, but the conditions that obtain in the commercial furnace are such that the impedances $x'y$ and xy' are equal and also that xy and $x'y'$ are equal. On substituting this condition, that $c = d$ and $e = b$, the general expression reduces to the following simple expression:

[illegible]

The condition for balanced power is that the impedance between the top electrode of one phase and the bottom electrode of the other phase be the geometric mean of the impedance between the top electrodes and the impedance between the bottom electrodes. When this type of furnace is properly designed the furnace transformers need not be of any special ratio of transformation, as is required by the other method for obtaining balanced power from a furnace equipped with bottom electrodes.

Direct-Current Crane Controllers

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CRANES of some form are used in practically every manufacturing establishment and in many other industries. They may be briefly classified as jib, gantry, traveling, tram or locomotive cranes. The function of a crane is to hoist or lower a load or move it from one position to another. Small cranes often have the hoist operated by hand. Larger cranes are operated by electric motors. These may be controlled from the floor or the operator may be located in a cage suspended from a portion of the crane structure.

The traveling crane is one of the best known types of power operated cranes. It consists of a bridge structure provided with a truck at either end, which travels on rails lengthwise of the building. On the bridge is a pair of rails supporting a trolley which moves back and forth from one end of the bridge to the other, the hoisting mechanism being mounted on the trolley. A crane of this kind uses at least three motors, one for moving the bridge, one for moving the trolley and the third motor for hoisting the load. Some trolleys are provided with two hoists, one known as the main hoist which lifts heavy loads at relatively slow speeds, the other the auxiliary hoist arranged for lifting light loads at high speeds. Some large cranes have two trolleys each with a main and auxiliary hoist, making a total of four hoisting motors, two trolley motors and one bridge motor or seven motors in all. Direct-current series motors are considered the best for this service. They require fewer trolley wires than alternating-current motors and usually have less inertia in their rotating elements. The series direct-current motor has a very desirable speed-torque characteristic. With light loads the speeds are high and with heavy loads considerable more than normal torque can be developed, for short periods of time, at relatively slow speeds. Due to these characteristics heavy loads can be lifted, when necessary, and at the same time considerable speed can be obtained in handling light loads.

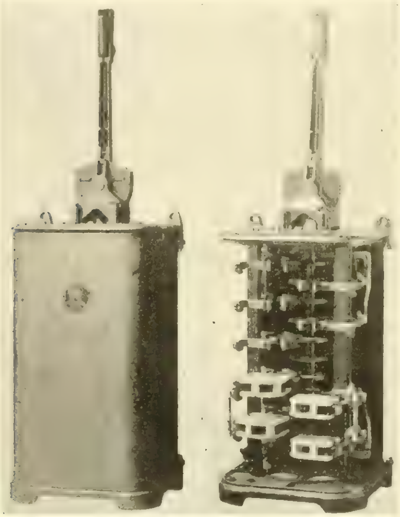

FIG. 1 CAM TYPE MANUAL CONTROLLERS

With and without cover. The individual cam units are shown in Fig. 3. Each unit is operated by a cam attached to the vertical shaft. A lever-type handle is used so that the forward motion of the handle can represent lowering and the backward motion hoisting.

Another very desirable feature of the direct-current motor is its use as a generator in lowering loads. This is known as dynamic braking and avoids the use of a friction brake for lowering the load. The heat developed by the motor may be more than when using a standard friction brake but this is more than compensated for by the reduced maintenance charge which is involved where friction brakes are used to absorb energy.

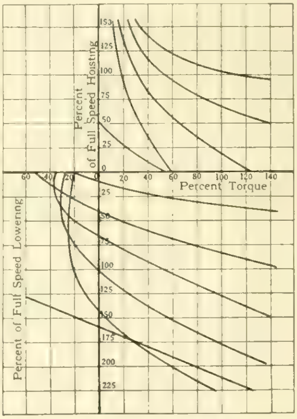

FIG. 2 SPEED-TORQUE CURVE OF A SERIES HOISTING MOTOR

These curves show five points hoisting and six points lowering. The curves above the zero line are for hoisting conditions and below the zero line for lowering. The lowering curves to the left of the zero line represent operation as a motor. The bottom curve, indicating a light hook requiring 20 percent of normal load, shows that 150 percent of normal speed can be obtained. Extensions of curves for lowering represent the motor operating as a compound-wound generator. Where a different number of notches is used, the top and bottom curves will be kept approximately as shown and the intermediate curves varied to suit the number of notches.

In addition to the direct-current series motors, the general purpose crane requires a controller for each motor and a limit switch and magnet brake for the hoist motors. In some cases overload protection is provided by a separate panel known as a crane protective panel. If the controller is of the magnetic type, the protective device can be included with the controller. In selecting the controller the choice lies between the manual and magnetic type. Each has its advantages and no general rule can be laid down for making a selection. The determining factors are the size of motor and the service requirements.

The manual controller has a less first cost than the magnetic, the wiring connections are simpler and the total weight of the control equipment is less. On the other hand, the manual controller requires somewhat more power to operate than a master switch of the magnetic type and the contacts are less durable, as the manual operation is not as positive as the magnetic. A manual controller does not provide for automatic acceleration or deceleration. The durability of the controllers bears a direct relation to the power required to operate. If the motor is large and the service severe, the magnetic controller should be selected on account of this durability. The small manual controllers and the larger ones applied to infrequent service are satisfactory, as the additional force required to move the handle is not important where the operations are infrequent.

The advantages of the magnetic type of controller consist in its durability, its ease of operation, the location of the arcing at a distance from the operator, and the small space required for the master switch, which enables the operator to observe the movements of the load more readily. This type provides automatic acceleration and deceleration, which is particularly desirable with large cranes. Where large motors are used it is desirable to have the arcing remote from the operator. The magnetic controller is heavier and occupies more space than the manual, its first cost is greater and the wiring connections are somewhat more complicated.

In many mills and other establishments, cranes are used for various purposes. Some of these cranes will have large motors and will be operated very frequently. Others will be smaller and used less frequently. It is, therefore, logical to use magnetic controllers on some cranes and manual controllers on others. In order to make it easy for the same set of electricians to take care of these different controllers, it is desirable for them to have as many features in common as practical. Manual controllers are now available which use the same diagram of motor connections as the magnetic type. The various sizes of controllers may differ in the number of resistor notches, but the scheme of connections is the same and the same resistors may be used for a given horsepower with either magnetic or manual controllers. If the number of resistance connections is different, the terminals on the resistors may readily be shifted to take care of this condition. The speed torque curves of the motors are identical, (Fig. 2), the highest and lowest speeds being the same for any controller and the intermediate speeds depending on the number of notches. Lever-type handles are used for both the manual controller and the master switch of the magnetic type; the forward movement lowers the load and the reverse movement connects the motor for hoisting. Details of these controllers have been worked out so that both the manual and magnetic types use the same contacts and the same arc boxes; the connections being identical, the same limit switches can be used.

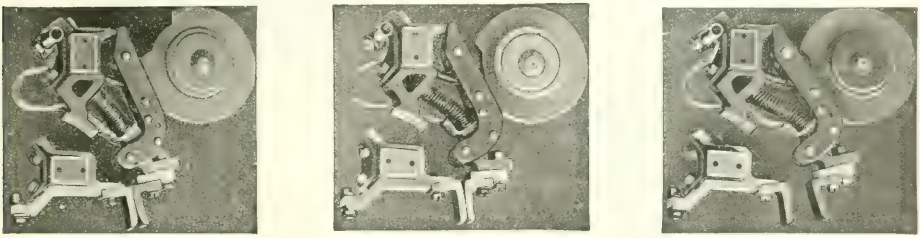

FIG. 3—DETAILS OF CAM CONTACTOR

Showing action of the contactor in opening and closing. The movable contact is mounted on an adjustable hinged member, so that the location of the contact can be set to give the proper rolling action.

In selecting controllers for a given installation, various sizes of motors should be tabulated and two or possibly three sizes of controllers selected for the entire range. These controllers can be so selected that the same size contacts and arc boxes will be used for the manual and magnetic types. This will reduce the spare parts required to a minimum. Ordinarily two sizes of contacts should give the proper range for an ordinary establishment.

The manual controller is illustrated in Fig. 1. It consists of a number of manually-operated contactors mounted in a frame which is of the same general shape and size as the drum controller. Each unit is separate and either the moving or stationary element can be readily taken out and replaced without disturbing other parts. The action of the contact is identical with the magnetic contactor and is illustrated in Fig. 3. The standard hoisting controllers are provided with the same number of units as the bridge and trolley controllers but differ in the arrangement of cams. Both controllers are of the same size and are identical with the exception of the cams and wiring connections. The contacts are carried on two brass pieces which are clamped together. The surfaces of these two pieces are corrugated, so that by loosening the clamping bolt, the contacts may be shifted forward or back in order to adjust for wear or variations in manufacture. If one of the cam units is replaced it is very easy to adjust the contact so that the proper rolling action is obtained. In the larger controllers the contactors are mounted on steel bars insulated with micarta. The smaller controllers have the contactor units mounted on micarta plates.

The magnetic contactor controllers are illustrated in Figs. 4 and 5. One of these has cast iron, the other pressed steel contactors; the latter has a new form of accelerating relay*.

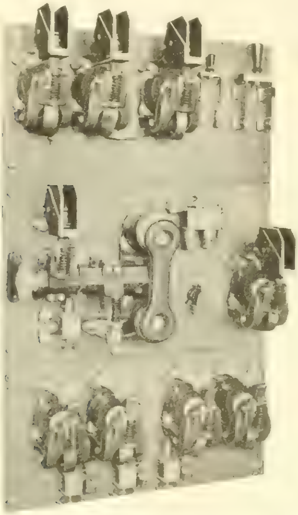
FIG. 4—MAGNETIC CONTACTOR CONTROL PANEL
Using cast iron contactors.

When the controller is in the off position, contact *6* (Fig. 7) is closed, providing a dynamic brake path through the series field and a small section of resistance. This low resistance gives a suitable braking torque for stopping from slow speed. If the operator should be lowering a heavy load at full speed and move from full speed quickly to the off position, he would get an abnormally heavy dynamic braking current and torque which might seriously strain his mechanical structure and at the same time throw an abnormal load on the electrical equipment. When a magnetic contactor controller is used, automatic deceleration is obtained with the same relays that provide acceleration if the controller is on one of the running notches. Ordinarily this is sufficient, as the operation of the crane requires a considerable amount of skill in handling the load and a good operator would not attempt to stop his load from full speed without first slowing it down, but in some installations it has been thought advisable to provide automatic deceleration when the controller is thrown to the off position from full speed with a heavy load. Several methods for accomplishing this have been proposed. One method is to provide relays connected across the motor armature which are held in by counter e.m.f. Relays of this kind are adjusted to drop out at the proper voltage but dirt and moisture may change the setting.

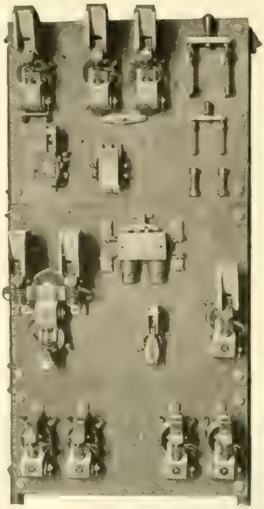
FIG. 5—MAGNETIC CONTACTOR CONTROL PANEL
Using pressed steel contactors and multiple finger relays.

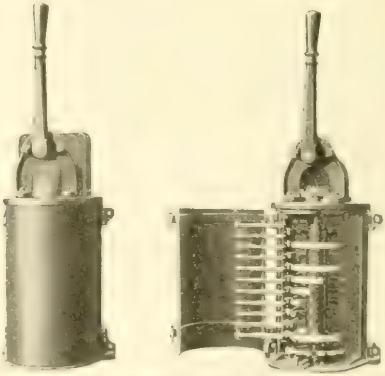
FIG. 6—SIX POINT MASTER SWITCH
This switch is of the drum type with a lever handle. It can be used with the controllers shown in Figs. 4 and 5.

Another scheme provides a two-pole, protective relay which is closed when the motor is operating at one of the higher speeds. This relay maintains the magnet circuits to contactors *2*, *4* and *5* so that these contactors remain closed and contactor *6* is kept open until the last resistance switch has been closed. If the controller handle is thrown suddenly from full speed to the off position, the resistance contactors close automatically in the same way as for acceleration, the current limit relays maintaining the dynamic brake current at its proper value. When the last contactor closes, it opens an interlock which opens the protective relay and allows the motor to be disconnected from the line and closes switch *6*.

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*Described in the JOURNAL for Feb., 1920, p. 51

Devices of this kind will guard against abuse to the controller but add some complication. They also prevent the operator obtaining the emergency stop in case of accident. It is, therefore, a question whether it is better to permit the operator to obtain emergency dynamic braking at will, relying on his judgment not to use it unnecessarily, or to add the complication of a protective relay.

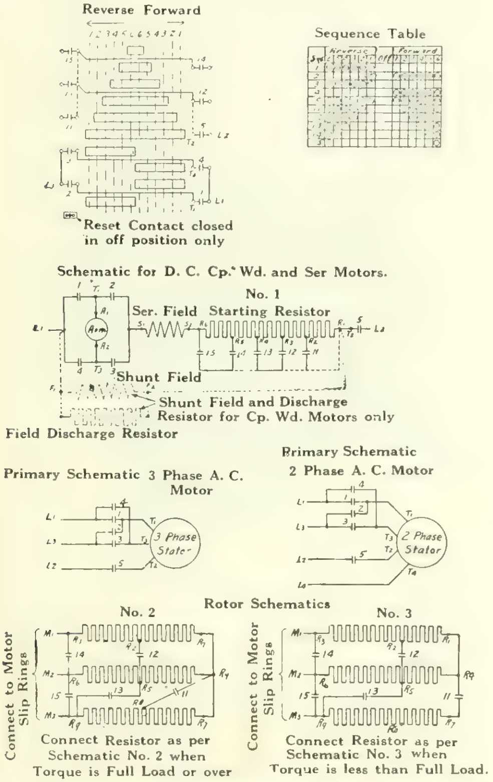
Reverse Forward
Sequence Table
Reset Contact closed in off position only
Schematic for D. C. Cp. Wd. and Ser Motors.
No. 1
Ser. Field
Starting Resistor
Shunt Field
Shunt Field and Discharge Resistor for Cp. Wd. Motors only
Field Discharge Resistor
Primary Schematic 3 Phase A. C. Motor
3 Phase Stator
Primary Schematic 2 Phase A. C. Motor
2 Phase Stator
Rotor Schematics
No. 2
No. 3
Connect to Motor Slip Rings
Connect Resistor as per Schematic No. 2 when Torque is Full Load or over
Connect to Motor Slip Rings
Connect Resistor as per Schematic No. 3 when Torque is less than Full Load.

FIG. 7—DIAGRAM OF CONNECTIONS FOR HOIST CONTROLLER

Manual controllers require the use of a crane protective panel for automatically disconnecting the motors from the line in case of overload. A panel of this kind is illustrated in Fig. 8. Two magnet contactors are provided which are actuated by a number of overload relays. There is one relay for each motor circuit and one relay in the common return circuit. If any one of the relays operates due to overload, it will open the magnetic contactors and cut the power off the crane. The magnetic contactors may be closed by pressing a reset button or the manual controller may be provided with means for resetting the contactors by moving the controller to the off position. Sometimes an emergency switch or button is provided for opening these contactors in case of accident.

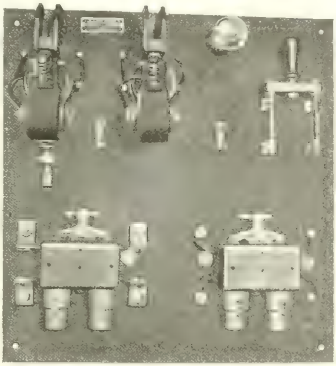

FIG. 8—CRANE PROTECTIVE PANEL

The protective panel is usually provided with a knife switch arranged for locking in the open position, also with a lamp receptacle connected to the line side of the knife switch, so that the repair man can attach a lamp cord to provide light when making repairs or inspecting the equipment. The overload and low voltage protective features provided by such a panel may be incorporated in the controller when it is of the magnetic type. Whether such a panel is used with magnetic contactor control depends upon local conditions and on personal preference. Such a panel, however, must always be used with manual controllers.

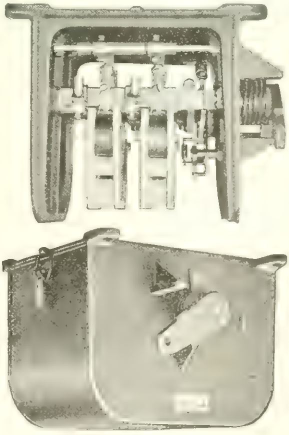

FIG. 9—CRANE LIMIT SWITCH

A limit switch should be included in every crane equipment, one switch for each hoist. These switches are so designed that the motor is stopped when the hook reaches a predetermined position in its upper travel. Limit switches are built in a number of different forms and types. They may either switch the motor direct or they may be in the form of a master switch which actuates contactors on a control panel or protective panel. The switch may be reset by reversing the controller, or it may require to be manually reset.

Fig. 9 illustrates a form of switch used to switch the main circuit of the motor. This is a two-pole, double-throw switch, the connections being illustrated in Fig. 7. The switch is located on the trolley, together with the dynamic brake resistance. When the hook reaches the upper limit of travel it lifts a weight which gradually moves the switch arm toward the safety position. After this arm has been moved far enough, it trips a catch inside of the switch, which causes one pair of contacts to open and the other to close. This disconnects the motor from the power supply and short-circuits the armature through a series field and an external resistance, which gives a quick stop by dynamic braking. By reversing the controller, the motor will operate the hook in the downward direction at a slow speed. This allows the weight to follow and restores the limit switch to its normal position by tripping a catch and moving the switch quickly to the normal position.

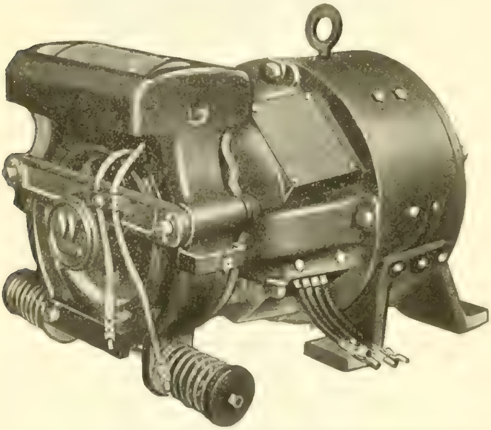

FIG. 10—SMALL MAGNET BRAKE MOUNTED ON THE END FRAME OF A CRANE MOTOR

When a switch of this type is used the circuit is opened at the motor and an emergency circuit established without the use of a pilot or auxiliary control circuit. If the limit switch is of the master switch type, at least one extra trolley will be required for a control wire and the emergency brake circuit would be fed through several trolleys, which introduces an additional hazard.

The switch described is automatically reset on reversing of the motor. Some designs of limit switch must be reset by hand. This means that the operator must leave the cab and climb up onto the bridge in order to reach the switch which is mounted on the trolley. It is pointed out that the inconvenience caused the operator is desirable, as it prevents him from running into the upper limits of travel and makes him more careful in manipulating his crane. On the other hand, the resetting of this switch causes the operator to expose himself to injury, and it is a question whether he should be subjected to this additional personal hazard. Devices can be used to indicate the number of times the limit switch has been operated and means taken to penalize the operator if it is thought necessary to do so.

The illustrations of the protective panel and the limit switch show that the contacts are the same as those used for the controller. The protective panel also has arc shields which are interchangeable with the controller. By making these items the same, the list of spare parts is reduced to a minimum.

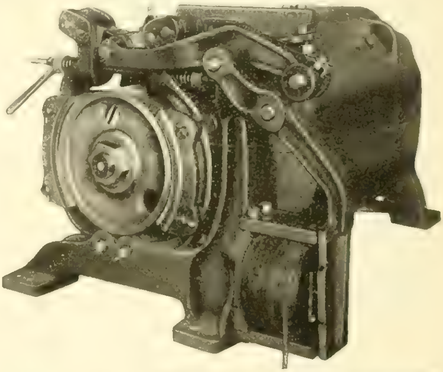

FIG. 11—LARGE BRAKE MOUNTED SEPARATELY FROM THE MOTOR

All hoist motors on cranes are equipped with magnet brakes. These are usually shoe brakes released by a magnet and applied by a spring. The magnets are usually series wound and are designed to release the brake at not over 40 percent of the rated current of the motor and to maintain the brake in the release position down to at least ten percent of the rated current of the motor. The coil should be connected in the circuit in such a way that no current will flow through it when the controller is in the off position. A few applications, such as ore bridges have a wider range of current than is usual with ordinary cranes and it is, therefore, necessary to wind the brakes with a shunt coil. In order to make brakes quick acting, the shunt coil has relatively few turns and is connected in series with a resistance. Sometimes an additional resistance is shunted across the coil to take up the discharge. Large brakes actuated with coils arranged in this manner are quick in operation, and are proving very satisfactory.

Smaller motors may be provided with brakes mounted on the motor frame, as shown in Fig. 10. Larger motors have the brakes separately mounted, Fig. 11. Both arrangements have their advantages and disadvantages. Ordinarily the small motor is easy to handle, as the entire motor, including the brake, can be taken off the crane and another one substituted when repairs are required. Larger motors are more difficult to handle and there is an advantage in having the brake mounted separately.

The brakes illustrated are provided with the clapper type of magnet. Older forms of brake had a magnet of the coil and plunger type, as this design theoretically is more economical, where a considerable travel is required. The objection to the coil and plunger is that an accumulation of dirt around the plunger may interfere with its operation; also the tendency of the plunger to pull sideways and cause abnormal wear. When properly designed, the clapper magnets have proved economical and they do not get out of order or clog up with dirt.

Parallel Operation of Gas Engine Driven Generators

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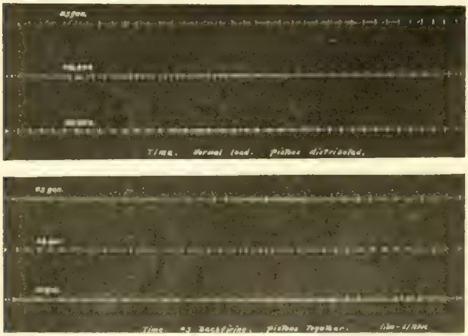
Alternating-current generators driven by gas engines are liable to cyclic fluctuations in load when operating in parallel. There are circulating or cross currents between the generators which may, under certain conditions, be of such magnitude as to cause excessive heating or excessive stresses in the windings. When the engines are supplied with gas of a varying quality, such as blast furnace gases, the large circulating currents may be of such frequent occurrence that the generator windings are subjected to a gradual weakening process which shortens the life of the machine. These facts were brought out in tests made in a steel plant with gas-engine driven generators operating in parallel, and in this article a few of the principal tests will be described and the results presented.

The plant at the time the tests were made contained five generators, one of them being of 1000 kw capacity and the other four of 2000 kw capacity. The 1000 kw unit, designated as No. 1, is a 2300 volt generator which is used principally for feeding a few motors and some lighting load. The 2300 volt bus, to which it is connected, is tied in by means of a 500 kv-a. transformer with the 6600 volt bus in the station. The four 2000 kw, 2350 kv-a., 36-pole units operate at 6600 volts, 25 cycles and are connected directly to the 6600 volt bus. The engines are driven from furnace gas and frequently are subject to premature firing on account of the variation in gas conditions. Particularly at times following a slip in one of the furnaces, the percentage of hydrogen in the gas is high and this tends to cause premature firing.

It was observed, during normal operation of the generators at a time when there was no premature firing, that the ammeter and watt-meter pointers swing violently, due to fluctuations in engine speed during the revolution. If the engines driving the generators in parallel have their crank shafts in the same relative positions, the swinging is more violent on the feeder meters than on the generator meters. This is because there are cyclic variations in voltage and frequency, causing heavy swings of current when feeding induction motors and synchronous apparatus, which tend to run at a constant speed. When, however, the engine shafts are in different relative positions, these cyclic variations of voltage and frequency are smoothed out at the bus-bars, reducing the swinging of the feeder meters considerably. In this case heavy, cyclic, cross currents are produced between the generators, causing the generator meters to swing. This condition is accentuated when there is premature firing on one or more of the engines.

In order to determine the actual magnitude of the cross currents, and the displacement between the rotors of the generators, oscillograph records were made. Three generators, No. 2, No. 3 and No. 5, were operated in parallel during the tests, and were connected to the 6600 volt bus, carrying the normal mill load. For some of the oscillograms, the cranks of the three engines were in the same relative position, or "symmetrical". For other tests the cranks were relatively displaced, or "distributed", so that the explosions did not occur simultaneously in the three engines. Premature firing was caused by advancing the spark on one cylinder of engine No. 3. Oscillograph records were taken both with and without premature firing occurring.

The measurement of angular displacement between the rotors of the generators was made by the use of contacting devices on the generator shafts. Around each generator shaft was placed a paper belt having thirty-six holes equally spaced. This gave a 10 degree spacing mechanically or a 180 degree spacing electrically between the holes. A metal contact strip bore on the paper belt and made contact on the shaft as each hole passed. This contact was connected in circuit with the oscillograph and the battery, so that as each hole passed under the contact a deflection of the oscillograph occurred. The records of the three generators were taken simultaneously and a comparison of the angular positions is then easily made from the oscillograms, two of which are reproduced in Figs. 1 and 2. The breaks in the three lines on the oscillograms show the instant of the making of the contacts through the holes in paper. The oscillograms were subsequently marked by placing dots on the line for No. 2 and No. 5 generators, these dots corresponding to the breaks in the line for No 3 generator. If there were no swinging or angular displacement between the generators, the position of the dots with respect to the breaks in the lines for No. 2 and No. 5 generator would be uniform. The variation of the position of the dots thus gives a measure of the angular displacement and can be measured in degrees by considering the distance between the breaks in the line as 180 electrical degrees.



FIGS. 1 AND 2—OSCILLOGRAMS SHOWING DISPLACEMENT OF GENERATOR FIELDS

An analysis of the records shows that identical conditions do not obtain in successive tests with premature firing, and it is possible that the worst condition obtainable was not reached at any time during the test. The records are given in Table I, with the conditions under which they were taken indicated as follows:—

TABLE I—RANGE OF ANGULAR DISPLACEMENT

Test	Condition	Generators 3-2 Electrical Degrees	Generators 3-5 Electrical Degrees
1	1	20	30
2	1	45	80
3	2	70	80
4	2	80	110
5	3	45	70
6	4	100	120
7	4	30	60
8	4	30	45
9	4	45	30
10	4	70	50

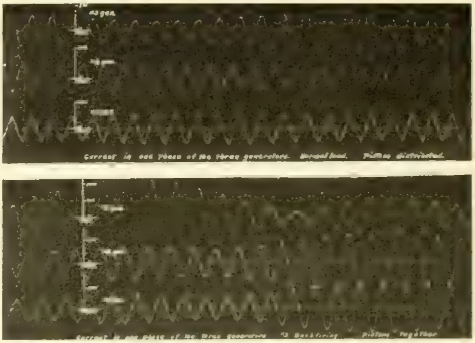
Condition 1—Normal load on the generators, engine pistons distributed.

Condition 2—Normal load on the generators, pistons distributed, No. 3 generator firing prematurely on one cylinder.

Condition 3—Normal load on the generators, pistons symmetrical.

Condition 4—Normal load on the generators, pistons symmetrical. No. 3 engine firing prematurely on one cylinder.

Under the same conditions, the currents in the generator leads were recorded by means of the oscillograph, records being taken on one phase of each of the three generators. The rated full-load current of the machines has a peak value of 290 amperes, and a comparison of this value with the actual currents measured shows the severe conditions under which the generators operate. The results of these tests are contained in Table II.



FIGS. 3 AND 4—OSCILLOGRAMS OF GENERATOR CURRENT
Showing fluctuations in current produced by the irregular speed.

The films which are reproduced in Figs. 1, 2, 3 and 4, are those taken for tests *1*, *6*, *11* and *17*, and are typical of the films taken during the tests. Figs. 3 and 4 show very clearly the swinging effect obtained in the generator current on account of the non-uniformity of speed of the generator revolution.

In addition to the oscillograph measurements, visual observations were made by looking through the revolving rotors of generators *3* and *2*, so as to obtain a stroboscopic effect and see the angular displacement between the field poles. The results obtained in this manner, while not highly accurate, checked closely with the angular displacement as recorded on the oscillograms.

TABLE II—MAXIMUM AMPERES—PEAK VALUE

Test	Condition	Generator 3	Generator 2	Generator 5
11	1	450	250	300
12	2	1200	500	850
13	2	1100	800	900
14	2	1400	1000	800
15	2	900	600	600
16	3	450	450	400
17	4	1150	600	600
18	4	500	500	450

The mechanical displacement of the rotating fields of the generators, as indicated by Figs. 1 and 2, does not exactly correspond to the magnetic displacement between the fields, because of a certain amount of shifting of the magnetic center of the poles away from the mechanical center when the generators are carrying load. The fact that there is a large magnetic displacement, comparable in amount with that measured by the mechanical means, is established, however, by oscillograms of the cross currents, as illustrated in Figs. 3 and 4.

Methods of Computing Machinery Foundations

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THE TERM FOUNDATION generally applies to that portion of a structure which serves as a support or a base on which to erect a superstructure. The word also applies to any built up structure supporting a downward or side pressure, regardless of shape or size, designed to carry a given load over a given area of soil, sand, muck, rock or substance of this nature.

The general purpose of constructing a foundation is to form a sufficient and solid base for the load to be supported, so that no movement will take place after its erection. Since it has been found that almost all of our soils will compress under heavy loads, it is natural to expect most foundations to settle to some extent, regardless of the materials used. The main object of the engineer, then, should be to limit this settlement and guard against uneveness of settlement.

BEARING VALUE OF SOILS

Before the bearing value of any soil can be determined, and before any important foundation structure is erected, the engineer should make a thorough test of the soil, either by drilling or digging test holes. Even with this precaution it may be possible to get an uneven settlement, as many soils vary in a comparatively small area, the strata seams being irregular in their elevations. Water is one of the most treacherous elements encountered in foundation work, and the bearing values of almost all soils, especially clay soils, are reduced very materially by moisture. When a condition of this kind develops, some method of draining the water away from the site of the foundation must be provided before the foundation is put in.

TESTING NATURE OF SOILS

For foundations for ordinary loads, the soil may be tested by a four inch auger and the borings examined as the soil is penetrated. This is a practical and cheap method of testing, both for condition of soils and moisture. Very often excavation is begun and continued until the engineer in charge is satisfied the soil will carry the necessary load. Where excavation is not necessary, tests may be made by loading one foot square pedestals up to the bearing capacity required. This type of testing should be done at several places to see if the soil is uniform. In making a test of this kind a permanent bench mark should be determined before the load is applied and accurate levels taken with an engineer's level as the load is increased, until the settlement reaches the maximum set.

The working load is generally taken at one-fifth of the load necessary to produce the maximum settlement, giving a safety factor of five, but where slight settlement will not be injurious, the safety factor may be reduced to three.

SAFE BEARING POWER OF SOILS

The values for the bearing power of soils, given in Table I, were prepared by Prof. Baker of the University of Illinois and have been generally adopted.

When foundations are built directly on solid rock, the surface should be cleaned of all loose rock or dirt and brought to a level surface perpendicular to the direction of pressure and a layer of rich cement motar placed directly on the cleaned rock, which will make a good bond between the rock and the foundation. Where sand or dry clay is encountered, the foundation need not be carried any deeper than below frost line.

Where marshy and wet soils are encountered, it is very difficult to spread the footer foundation sufficiently to carry the load and concrete or wood piles are used. They make a most reliable, though somewhat expensive base. The safe carrying load of a pile is very hard to determine exactly, as many conditions are encountered that weaken the pile in driving. Great care should be used in driving piles where small penetrations are obtained, as the last blow may smash or shatter the pile. The engineer in charge should be able to judge very closely as to the bearing power of the pile. Formulas for safe bearing powers of piles are simply aids to judgment and should not be followed blindly.

TABLE I—SAFE BEARING POWER OF SOILS

Kinds of Materials	Safe Bearing Power in Tons per Sq. Ft. Minimum	Safe Bearing Power in Tons per Sq. Ft. Maximum
Rock—hardest in thick layers in bed..	200	
Rock equal to best ashlar masonry..	25	30
Rock equal to best brick masonry...	15	20
Rock equal to poor brick masonry....	5	10
Clay in thick beds, always dry.......	4	6
Clay in thick beds, moderately dry...	2	4
Clay, soft	1	2
Gravel and coarse sand well cemented	8	10
Sand compact and well cemented....	4	6
Sand clean, dry	2	4
Quick sand, alluvial soils, etc.	0.5	1

Formulas for the bearing power of piles determine the safe bearing power from the weight of the hammer, the length of free fall of the hammer and the penetration of the pile. The *Engineering News* formula for the safe bearing power of piles is accepted by many as reliable.

$$P = \frac{2wh}{S+1}$$

Where,
P = Safe load on piles in tons.
w = Weight of hammer in tons.
h = Distance of free fall of hammer in feet.
S = Penetration of pile for the last blow in inches.

This formula gives a safety factor of about 6. Piles are usually driven in clusters about three foot centers and the foundation started on a heavy concrete cap resting on the heads of the piles and bonded with anchor rods which project above the pile heads. There are many patented designs of concrete piles on the market, and the type of pile most suitable should be determined by the natural conditions of the locality.

CHARACTERISTICS OF CONCRETE

Concrete is made up of cement, sand, gravel or broken stone and water; and the method of mixing, while looking simple, requires constant supervision, as one bad mix may result in wrecking a structure. There are a number of methods used in mixing concrete. Mechanical mixing is much superior to hand mixing which should be used only where the job is not large enough to justify the expense of a mechanical mixer.

There are two kinds of cement, natural and artificial. Natural cement is made from a cement rock burned and finely ground and weighs from 50 to 55 pounds per cubic foot. This cement sets more quickly than artificial cement. Artificial or portland cement is made from clay and finely pulverized carbonate of lime, or compact limestone, burned to a clinker in a high temperature kiln and the clinker then ground to a fine powder. This cement is very uniform in color and weighs 80 to 90 pounds per cubic foot. There are many brands of cement on the market, all of which are about equal in quality. As they all have to conform to certain standards that have been fixed by cement manufacturers, there is very little risk in using any well-known brand of cement. There is however, considerable difference in the time of cements in setting, and where it is necessary to hurry work along, this feature should be looked into. Portland cement is about 30 percent stronger than natural or rock cement.

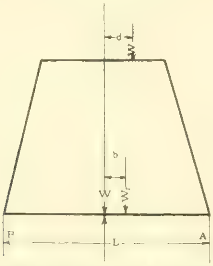


FIG. 1 — LOADS APPLIED TO A FOUNDATION

MIX OF CONCRETE

Concrete for most heavy foundations should be proportioned as follows: 1 part cement, 2 parts sand and 5 parts gravel or broken hard stone, with sufficient clean water to make a mortar that will adhere to the aggregates. After concrete is put in place and puddled, water should flush to the surface. Concrete should be put in place as soon after mixing as possible, as setting under ordinary conditions, begins within 20 to 30 minutes after water is added. All aggregates should be free from clay or other foreign materials, and the water should be clean and about 50 to 80 degrees F in temperature.

COMPUTING FOUNDATION PRESSURES OF PIERS

In Fig. 1 let W represent a load applied on the foundations, d the distance from center line, w the weight of the pier acting through the center line and W_r = the resultant load acting at a distance b from the center line of the pier.

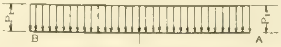


FIG. 2 — PRESSURE DUE TO DIRECT LOAD

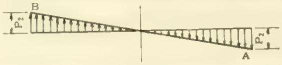


FIG. 3 — PRESSURE DUE TO BENDING MOMENT

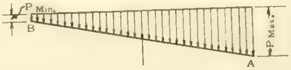


FIG. 4 — SUM OF PRESSURES DUE TO DIRECT LOAD AND BENDING MOMENT

$$b = \frac{W\left(\frac{L}{2}+d\right)+\frac{wL}{2}}{W+w}$$

Assuming that the base of the pier is a rectangle with a length L and a width of unity, the pressure on the foundation will be that due to the direct load W_r and a couple with an arm b and a moment $= + W_r b$. The pressure due to the load $W_r = P_1 = W_r \div L$, as shown in Fig. 2. The pressure due to the bending moment, $M = W_r b$, will be (from fundamental flexure formulae) $P_2 = \frac{MY}{I} = \frac{6\,W_r\,b}{L^2}$ as in Fig. 3. Where M = moment of the load about the center of gravity, Y = distance from the center of gravity to the edge and I = moment of inertia. The pressure at A will be, $P_{\max} = P_1 + P_2 = \frac{W_r}{L} + \frac{6\,W_r\,b}{L^2}$ and at B will be,— $P_{\min} = P_1 - P_2 = \frac{W_r}{L} - \frac{6\,W_r\,b}{L^2}$ as in Fig. 4.

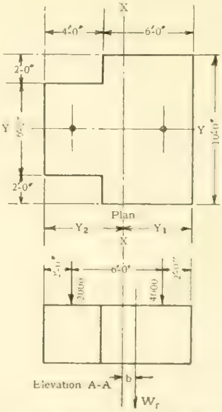


FIG. 5 — A TYPICAL T SHAPED FOUNDATION

Now if the base of the pier be a rectangle and the eccentricity b is equal to $L \div 6$,

$$P_{\max} = \frac{W_r}{L} + \frac{6 W_r \frac{L}{6}}{L^2} = \frac{2 W_r}{L}$$

$$\text{and } P_{\min} = \frac{W_r}{L} - \frac{6 W_r \frac{L}{6}}{L^2} = O$$

If b is greater than $L \div 6$, P_{Max} will be greater than twice the average load and P_{Min} will be tension. Since neither masonry nor foundation can take tension, this leads us to the theory of the "middle third", or kern, of a rectangular section.

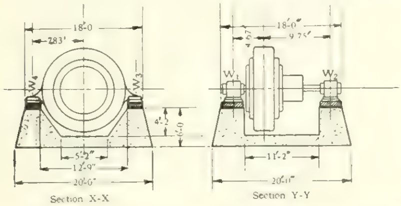


FIG. 6—SECTIONS THROUGH A FOUNDATION FOR A 1500 HP MOTOR

> "If the point of application of the load never falls outside the middle third of the section, there will be no tension between the masonry and foundation and the maximum compression will never exceed twice the average compression."

The criterion, then, for stable rectangular piers is that the point of application of all loads falls within the middle third, so that, $P_{\text{Max}} \leq \frac{2 W_r}{L}$

For other than rectangular piers the fundamental formula, $P = \frac{W_r}{L} \pm \frac{M}{I}$ can be used, but it still must be remembered that P_{Min} must be a positive quantity.

To illustrate, the T-shaped foundation, Fig. 5, with loads as shown, will be solved for the maximum and minimum pressures on the foundation. The first step is to locate the center of gravity of the area, Y_1 or distance from the back of the T to the center of gravity.

$$Y_1 = \frac{3(6 \times 10) + 8(6 \times 4)}{(6 \times 10) + (6 \times 4)} = 4.428\ ft. \quad Y_2 = 10 - 4.428 = 5.572\ ft.$$

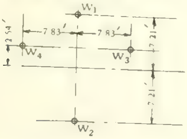


FIG. 7—APPLICATION OF LOADS IN FIG. 6

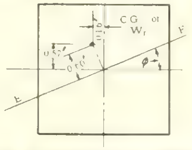


FIG. 8—DIAGRAM OF RESULTANT LOAD AND ECCENTRICITY

Then I or moment of inertia of the area, about axis X-X =

$$\frac{10 \times 6^3}{12} + 10 \times 6\,(4.428 - 3)^2 + \frac{6 \times 4^3}{12} + 6 \times 4\,(5.572 - 2)^2$$

$$I = 640.55\ ft.^4$$

$Area\ of\ foundation = 10 \times 6 + 6 \times 4 = 84\ sq\ ft$

$W_1 = 20\,000\ lbs.$

$W_2 = 40\,000\ lbs$

$W_f = 10 \times 6 + 6 \times 4 \times 150 \times 4 = 50\,400\ lbs$

$W_r = 20\,000 + 40\,000 + 50\,400 = 110\,400\ lbs.$ and acts at

$$b = \frac{(40\,000 \times 2 + 20\,000 \times 8 + 50\,400 \times 4.428)}{110\,400} - 4.428 =$$

$- 0.218\ ft.$

Then,

$$P_{\text{Max}} = \frac{110\,400}{84} + \frac{110\,400 \times 0.218 \times 4.428}{640.55} = 1576\ lbs$$

$$P_{\text{Min}} = \frac{110\,400}{84} - \frac{110\,400 \times 0.218 \times 5.572}{640.55} = 1101\ lbs$$

Both of which are safe pressures per square foot for ordinary soils.

The pressures calculated in the preceding example are the maximum and minimum pressures if the loads are symmetrical about the Y-Y axis. To illustrate a case where they are not symmetrical, the following case, an actual installation, will be solved for P_{Max} and P_{Min}. This installation consists of a 1500 hp, 162 r.p.m., constant speed, non-reversible motor, whose dimensions are given in Figs. 6 and 7.

WEIGHTS OF PARTS

Frame	43 000
Rotor	48 500
Pedestals (each 8500)	17 000
Bed plate	33 100
Details	3400
Concrete at 150 lbs. per cu. ft.	262 500
Total dead load	407 500

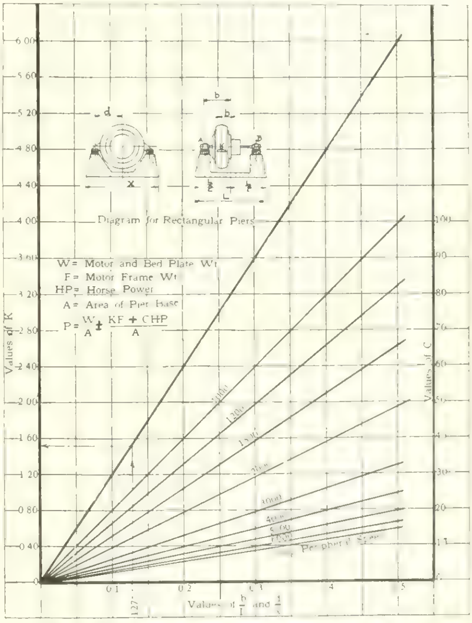


FIG. 9—VALUES OF CONSTANTS FOR RECTANGULAR PIERS

The weight of the bedplate and details may be considered as being equally distributed and may be added to the weight of the pier.

Bed plate		33 100
Details		3400
Concrete pier		262 500
	W_1 =	299 000
	W_1 =	41 300
	W_2 =	24 200
One-half weight of frame minus 50 percent of torque applied at mean radius of the foot	= W_3 =	17 375
One-half weight of frame plus 50 percent of torque applied at mean radius of the foot	= W_4 =	25 625
Total load	W_r =	407 500

Taking moments about X-X and considering W_1 as producing minus moments, the center of gravity of W_r is found to be — 0.57 ft. from the center line of the pier.

Taking moments about Y-Y and considering W_4 as producing minus moments, the center of gravity of W_r is found to be — 0.16 ft. from the center line of the pier, as shown in Fig. 8.

Now an axis E-E, Fig. 8, drawn through the center of the pier, perpendicular to a line drawn from the point W_r to the center will make an angle with axis X-$X = \phi$, and the lever arm of W_r about E-$E = 0.6$ ft.

The moment of inertia* I of the area about E-$E =$ 13 327 feet^4.

The distance Y from the extreme corner to E-$E =$ 12.27 ft.

The moment M of W_r about E-$E = 244\,500$ ft. lbs.

The area A of the base $= 400$ sq. ft.

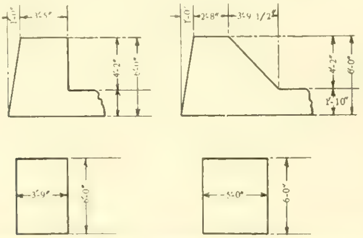
Then the foundation pressures are,—

$$\frac{W_r}{A} \pm \frac{MY}{I}$$

$P_{\text{Max}} = 1244$ lbs. per sq. ft. at corner A.
$P_{\text{Min}} = 784$ lbs. per sq. ft. at corner B.

REINFORCING OF CONCRETE

Generally, machinery foundations, because of the disposition of the material, require very little reinforcement, though it is the habit of designers not familiar with concrete work to put in a lot of unnecessary steel as reinforcing. The foundation previously discussed will now be investigated as to its reinforcement requirements. It will not be necessary to go into great refinements of mathematics to determine stresses, and the method given below will be found to be sufficient in practically all cases.



FIGS. 10 AND 11—SECTIONS THROUGH TRAPEZOIDAL PIT WALLS AND CORRESPONDING RECTANGLES

Passing sections through the foundation, the pit walls are found to be roughly trapezoidal in shape, and with dimensions as shown in Fig. 10. The corresponding rectangles are roughly approximated in Fig. 11.

Moments of Inertia,—

$$I = \frac{45 \times 72^3}{12} = 1\,400\,000 \textit{ inches}^4$$

$$I = \frac{60 \times 72^3}{12} = 1\,870\,000 \textit{ inches}^4$$

Using 160 lb. per sq. in. for the safe tensile stress of plain concrete in flexure, the allowable bending moments for a and b are,—

$$a = \frac{1\,400\,000 \times 160}{36 \times 12} = 520\,000 \textit{ ft. lbs.}$$

$$b = \frac{1\,870\,000 \times 160}{36 \times 12} = 700\,000 \textit{ ft. lbs.}$$

and the approximate actual bending moments are,—

$$a = \frac{W_1 \times 20}{4} = \frac{41\,300 \times 20}{4} = 206\,500 \textit{ ft. lbs.}$$

$$b = \frac{W_1 \times 1254 \times 1254}{20 \times 2} = 125\,600 \textit{ ft. lbs.}$$

Which shows that the walls are safe as beams without reinforcing.

The only thing left is the slab in the bottom. The bending moments in slabs fixed around the perimeter are very difficult to determine, but the formula,—

$$M = \frac{WL}{24}$$

may be used as an approximation where $W =$ total load and $L =$ one-half the sum of the length and breadth of the slab and each equals the clear span plus twice the thickness of the slab.

In this case the length equals 11 ft. 2 in. + 2 (1 ft. 10 in.) = 14 ft. 10 in. and breadth = 5 ft. 2 in. + 2 (1 ft. 10 in.) = 8 ft. 10 in. and

$$L = \frac{23 \textit{ ft. } 8 \textit{ in.}}{2} = \textit{11 ft. 10 in., say 12 ft.}$$

Then,—

$$W = \textit{Average unit load} \times \textit{slab area} = 1\,000 \times 12 \times 12 = 144\,000 \textit{ lbs.}$$

$$M = \frac{WL}{24} = \frac{144\,000 \times 12}{24} = 72\,000 \textit{ ft. lbs.} = 864{,}000 \textit{ inch lbs.}$$

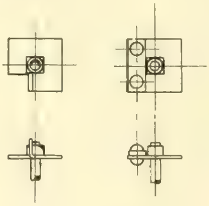


FIG. 12—NUT LOCKS

For a beam 12 ft. by 1 ft. 10 in. deep, the moment of inertia $= \quad I = \frac{144 \times 22^3}{12} = 128\,000 \textit{ inches}^4$

and the average unit flexural stress =

$$\frac{864\,000 \times 11}{128\,000} = 70 \textit{ lbs. per sq. in.}$$

which is safe, but should not exceed 80 lbs. without reinforcement in slabs fixed around the perimeter.*

To aid the man in the field, who seldom has time to analyze a foundation as thoroughly as has been done in the previous example, the diagram, Fig. 9, was devised. As the sum of the moments due to the frame weight and bearing loads equals approximately twice the moment of the frame weight about the center line, the values of K have been made equal to twice their true values. This makes it possible to determine with sufficient accuracy the pressure due to both the frame and bearing loads. If greater accuracy is desired, halve the value of K and multiply the weight of the frame by this new value of K and the load on bearing A in excess of that on bearing B by one-half the value of

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*For methods of determining I for various sections, reference may be made to Carnegie Steel Company "Pocket Companion" or any standard work on mechanics.

*Where reinforcement is required the reader is referred to "Reinforced Concrete Beams and Floor Slabs," Carnegie Steel Company Pocket Companion, or standard works on reinforced concrete.

K obtained by using b' for b and adding the products. This sum divided by the area of the base will be the pressure resulting from the moments of the frame and bearing loads.

In all cases the pressure due to the torque of the motor is equal to $C \times HP$ divided by the area of the base, and the maximum pressure equals the sum of these two quotients plus the weight of the machine, divided by the area.

The data necessary to use the diagram is usually to be found on the outline drawings of the motor.

To illustrate, the preceding problem will be solved with the diagram, using the values of b, d, L and X, and the weights given. The speed of the motor is approximately 6000 ft. per min. b/L equals 0.127 and entering the diagram at the top with this value it is found to intersect the value of $K = 1.52$ at the line marked *"All Frames"*. d/X equals 0.39 and proceeding as before the value of C corresponding to a speed of 6000 ft. per min. is found to equal 13.

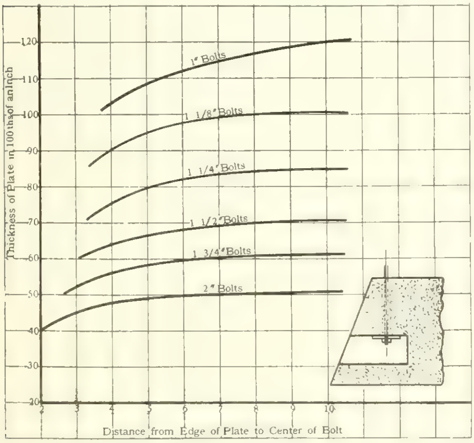

FIG 13—THICKNESS OF ANCHOR PLATES FOR TUNNELED ANCHORS

Then

$$P = \frac{145\,000}{400} + \frac{1.52 \times 43\,000 + 13 \times 1500}{400} = 575 \textit{ lbs. per sq. ft}$$

To this must be added the pressure due to the assumed pier, which in this case equals 656 lbs. per sq. ft., and the resultant maximum pressure on the foundation equals $575 + 656 = 1231$ lbs. per sq. ft., or one percent less than that obtained by calculation, and the minimum pressure equals 807 lbs. per sq. ft., or about one percent more than obtained by calculation.

If it is desired to equalize the pressures more nearly, it is possible to do so by increasing either the depth of the pier or the area of the base, though the latter is more economical. To illustrate, we will increase X to 26 ft. in this problem. The pressures are then 1114 and 806 lbs. per sq.ft., or a difference in pressures of 27 percent against a difference of 34 percent. Increasing the depth of the foundation by adding the same amount of concrete without increasing the area, will result in a difference of pressures of 29 percent, which shows that increasing the area rather than the depth is decidedly the more economical method of equalizing the pressures.

For slow-speed, reversing-type mill motors, the maximum foundation pressure should not exceed the average pressure by more than 50 percent in any case, and where the maximum pressure approaches the safe bearing power of the soil a difference of ten percent should be the maximum allowed, as the effect of the reversal of pressures is to rock the pier, where the soil is compressible.

ANCHORAGE

The usual method of anchorage is by anchor bolts built into the pier. The diameter of these bolts depends upon the load to which they are subject and the anchorage upon the strength of the bolts, as the anchorage of bolts should be sufficient to develop the full strength of the bolt. The depth to which anchor bolts are embedded is governed usually by the depth of the concrete, and a method of determining the required anchorage will be given. The shearing strength of concrete is 40 lbs. per sq. in., the bonding strength for plain bars is 80 lbs. per sq. in. and for bars with hooked ends bent 180 degrees around a radius of three diameters is 100 lbs. per sq. in.

A 1⅛ in. anchor bolt will be investigated to determine the necessary depth of anchorage.

Working strength of bolt at 16 000 lbs. per sq. in. = 11 000 lbs.

If a plain round bar were used the required depth would be $\frac{\textit{Working strength}}{\textit{Bond of concrete}} = \frac{11\,000}{80} = 137.5$ in.

For a bar with hooked end the required depth would be, $\frac{11\,000}{100} = 110$ *in.*

To realize this depth of anchorage requires very long and uneconomical rods and a plate anchorage is resorted to. This is accomplished by placing a plate washer of the proper size on the lower end of the rod and embedding it in the concrete. Then the anchorage is governed by the shearing strength of the concrete rather than the bonding strength. No set rule for the thickness of anchor plates can be given, but from 5/16 to ½ in. is a good thickness.

Let us consider that in the case of the 1⅛ in. anchor bolt the maximum depth of concrete is 20 in. As the plate and nut should be embedded in the concrete to protect them from the action of the ground water, the available depth is about 17 in. It is necessary to decide what size plate to use.

The shearing strength of concrete = 40 lbs. per sq. in.
The strength of the bolt = 11 000 lbs. per sq. in.

Then the necessary area in shear =

$$\frac{11\,000}{40} = 280 \textit{ sq. in.}$$

Now the depth of the anchorage = 17 in., so the perimeter of the plate must equal 280 ÷ 17 = 17 in. about.

A plate 4½ in. square by ⅜ in. thick will be used, having a perimeter of 18 in. and giving an area of 17 by 18 in. = 306 sq. in. of concrete in shear.

It is customary with some designers to provide a nut lock on anchor plates. This seems to be unnecessary, but two methods are given in Fig. 12. The first consists of shearing and bending up one corner of the plate so that it will engage the nut face; the other consists of an extra plate or bar riveted alongside the nut, so as to prevent turning.

On large reversing mill motors, the anchor bolts in certain positions are arranged so that access may be had to the anchor plates by means of tunnels. Where tunnelling is resorted to, the problem of anchor plates is a different matter than where the plates are completely embedded, and the chart in Fig. 13 is recommended for determining the thickness of plates required. In all cases care should be taken to have the depth of anchorage sufficient to develop the strength of the bolt.

Industrial Type Electric Locomotives

In Steel Mill Operations

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BEGINNING with the mining of the raw material and the mining of the coal as fuel, and ending with the various final manufactured products, there are a large number of stages in the manufacture of steel products, in all of which use is made of the industrial electric locomotive. A tabulation of the more important uses illustrates the wide range of application:

1—*At the Ore Mines*:—
  a—Hauling ore from mine to points of storage or shipping.
  b—At ore bins and ore bridges in the spotting of cars to receive the ore for shipment by rail, where shipment is made direct from mines.
2—*From Points of Storage*:
  a—Spotting of ore cars under ore bridges.
  b—Making up ore trains for shipping to mills.
3—*Reception of Ore at Mills*:
  a—Hauling ore from ore bridges and storage to furnaces.
4—*Intermediate Operations at Steel Mills*:—
  a—Handling of charging boxes on furnace charging floors.
  b—Hauling of ingots from pouring floor to strippers.
  c—Hauling of plates from heating furnaces to shears.
  d—General utility work in handling of fuel and fluxing material from storage bins to the scales and charging floors, also in handling of slag from the furnace.
5—*At the Coal Mines*:—
  a—Coal gathered at mine rooms.
  b—Coal hauled from rooms to shaft or slope.
6—*At the Coking Plants*:—
  a—Charging of bee hive ovens.
  b—Hauling of coal from coal bridges to by-product coke ovens.
  c—Hauling of hot coke from coke ovens to quenching tower and from there to screening stations.
  d—Making up and hauling coke cars from screening and loading stations to classification yards and points of shipment to mills.

At the iron ore mines, the ore must be gathered in the ore cars and hauled either direct to the mills or to a point intermediate in the shipment to these mills. In either case the ore is handled from the mines to the yards where the ore cars are classified. This is being done more and more by the industrial type of electric locomotive, the ease and flexibility in operation and the quicker and more efficient means of operating being determining factors.

At the ore bins, either at the mines or intermediate storage points in the transportation of the ore from the mines to the mills, the ore must be loaded onto the ore cars. This requires accurate and quick spotting of the cars to receive the ore. When the ore is received at the mills it is again stored and similar loading of the ore cars is necessary in preparing shipment in the final stage of transportation.

POLING LOCOMOTIVES

Poling locomotives for ore docks, loading stations and classification yards in the steel plants represent a class of locomotive which has come into common use within the past few years. The poling arms are located at each side of the locomotive. When lowered to the operating position they extend to the side and are of such a length as to reach standard ore or freight cars on tracks adjacent to the one on which the poling locomotive is operating. These poling arms are operated by air pressure controlled from the cab of the locomotive. They are of such a design as to engage the bumper of the car or cars being pushed and the load will be transmitted to the poling locomotive side frames through heavy springs located horizontally on both sides and at the base of the poling arm. Such a type of locomotive permits accurate and quick spotting of a car or a train of cars successively under a hopper, shovel or loading chute. Spotting of cars by this means is more accurate than when attempting spotting by a locomotive at the end of and on the same track as the cars, since the poling locomotive is operated on an adjacent track, and the motorman from his operating position can view the hoppers and material being loaded into the cars.

Current is collected by means of a shoe coming in contact with a protected third rail, located midway between the two traction rails. Electropneumatically operated unit switch control equipment is used in the locomotives shown in Fig. 1. Series-parallel control, obtained by the operations of a master controller and responding operations of the electropneumatic switches, gives the wide range of speed control desired in this class of service.

Inherent features of the electric type of locomotives are:—no interference in spotting from smoke and steam obstructing the view; operators at the hoppers and loading chute work under better conditions, due to the absence of smoke, steam and gases.

HOPPER CARS

In the handling of the ore from the ore bridges or points of storage a type of car similar to that shown in Fig. 2 is used. This is a large hopper car, which is motor driven and controlled from the cab at one end of the car. The car is of such a construction that upon opening the pneumatically operated doors at one side, the ore will be discharged by gravity from the car. These doors are also controlled by the operator in the cab. Cars of this type are in service with quadruple 75 hp, 250 volt motors and electropneumatically operated control for accelerating and for giving electric braking in addition to the air brake equipment. In a number of installations, current is collected from a metallic return system of power rails located at one side of the track, and in other installations current is collected from an overhead trolley or overhead power rails.

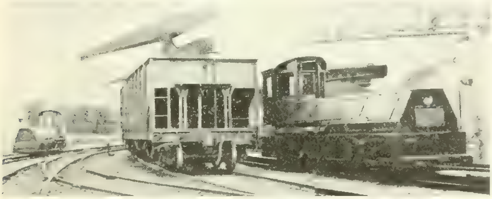

FIG. 1—PUSH POLE LOCOMOTIVE IN USE AT ORE DOCK
Showing poling arms extended and pushing a train of cars on an adjacent track.

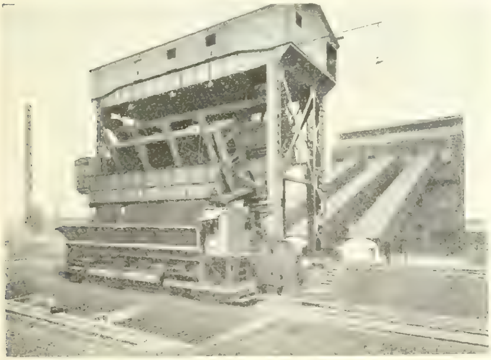

FIG. 2—MOTOR DRIVEN HOPPER CAR
For handling ore and coal from car dumpers and ore bridges to storage bins, furnaces, etc.

CHARGING FLOOR LOCOMOTIVES

Locomotives of the type shown in Fig. 3 are used on charging floors of open hearth furnaces. The design does not differ greatly from other types of industrial electric locomotives. As a rule the length of haul is comparatively short. While the charging boxes are being lifted from the charging cars, constituting the load being handled by the locomotive, the locomotive stands idle except for times of spotting the charging box cars opposite the furnace doors. The electric locomotive in this service, as in other service, has no standby losses during these idle periods. A very important feature in the way of bettering conditions and thereby increasing the efficiency of work carried on about the plant, is the absence of smoke, steam, gases and noise which, with steam locomotives, are all present. The electric locomotive is controlled with considerably greater accuracy and safety and considering that the charging floors are usually from 15 to 25 feet above the ground floor and the locomotive runs close to the end of this platform, this accuracy of control is of considerable importance from the standpoint of safety.

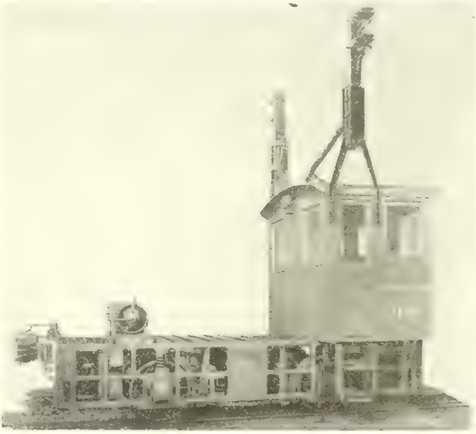

FIG. 3—TYPE OF LOCOMOTIVE USED ON CHARGING FLOORS
And in hauling ingot cars, ladle cars and slag cars.

The control equipment on locomotives of this type has been either of the hand operated drum type, or the electropneumatically operated type operated from a master controller in the cab of the locomotive. In the locomotive illustrated, air brake equipment in addition to the hand brake equipment is employed. In the majority of installations the current is collected from overhead power rails by current collectors of the contact shoe type. These are usually required to be mounted on a contact shoe beam supported on a frame constructed to suit the particular location of the power rails with respect to the locomotives.

INGOT BUGGY LOCOMOTIVES

Ingot buggy locomotives are usually of the same class as the charging floor locomotives, and are used to haul the ingots to the strippers. As with the charging floor locomotives, accurate spotting of the ingots under the ladles of molten metal is necessary from the standpoint of safety and quick operation. In taking the ingots to the stripper and returning to the pouring floor the locomotives should be capable of obtaining good speed within the safety of handling molten metal. Smooth accelerating of the locomotive and train is essential and again the electric locomotive with properly designed control equipment meets the requirements in this respect, as well as affording the greater efficiency in operating.

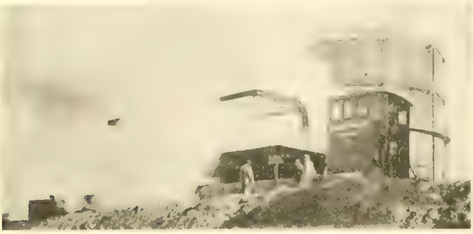

FIG. 4—AN EARLIER DESIGN OF QUENCHER CAR LOCOMOTIVE
Showing coke being quenched at quenching station.

COKING LOCOMOTIVES

In the manufacture of coke in the older beehive type of ovens, small motor driven larry cars are used for charging the ovens and from the ovens the coke is conveyed and loaded into the cars. In the more modern by-product plants, electric locomotives are used in handling the coke during the various stages in preparing the product for shipment. The close schedule of operation in all the stages of manufacture up to the time the coke is discharged from the ovens, requires that the operations in handling the coke from there on must also be carried forward on a close schedule basis, without failure to maintain this schedule day in and day out.

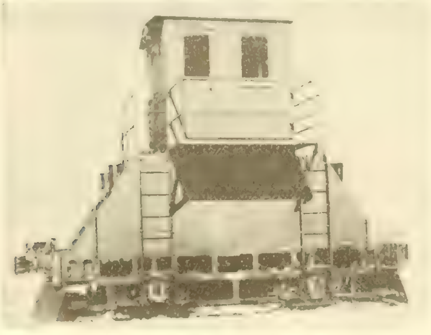

FIG. 5—A LATER TYPE OF QUENCHER CAR LOCOMOTIVE

QUENCHER CAR LOCOMOTIVES

Quencher car locomotives are used in hauling the coke in a special quencher car from the discharge end of the by-product ovens to a quenching tower, where the coke is quenched without removing it from the car. From here the coke quencher car is hauled to a coke wharf onto which the coke is discharged by opening the pneumatically operated doors at the side of the quencher car. These doors are controlled by and operated by air supplied from the motor driven air compressors on the locomotive, which also supply air for the air brakes on the locomotive and quencher car. Fig. 4 shows an earlier type of quencher car locomotive and an earlier method of quenching the coke. The figure illustrates the cloud of steam generated upon quenching the red hot coke.

Fig. 5 illustrates a later type of quencher car locomotive weighing 25 tons and equipped with two-75 hp, 250 volt direct-current, series-wound motors. The high control cab permits the motorman to view the quencher car and the discharging of the coke into the car, as well as the operations during the quenching of the coke at the quenching tower. The locomotive cab is divided into two compartments. The upper compartment, which is the motorman's compartment, contains the motor control equipment and air brake levers, as well as the air gauges and the levers for controlling the air operated doors on the quencher car. The lower compartment contains the two motor driven air compressors, (each having a capacity of 50 cu. ft. of air per minute) the air reservoir, and the main circuit control equipment, consisting of the contactors and motor cutout switches as well as the main and control resistors.

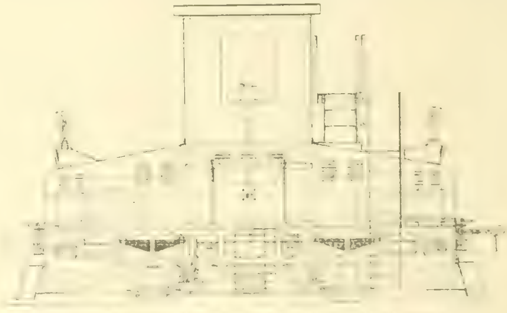

FIG. 6—[illegible] QUENCHER CAR LOCOMOTIVE

Fig. 6 shows the general outline and details in design of the latest type of quencher car locomotive, which embodies a large number of features in construction to withstand the severe service, also incorporating features in the layout of the equipment and methods of controlling the locomotive which were lacking in previous designs. The equipment on this locomotive consists of,—

Two 75 hp, 250 volt motors;
Two motor driven air compressors, each having a capacity of 50 cu. ft. of air per minute;
One master controller for controlling the electro-pneumatically operated switch groups; and other details for operating and controlling the air brakes, quencher car doors, air whistle, cab and compressor compartment lighting, and headlight.

The underframe construction of this locomotive is of the center sill type, rigidly braced to the side frames which are of bar steel construction. The steel cab, centrally located over the underframe, and the hoods at both ends are of heavy steel plates, not only for stiffness, but to prevent rapid corrosion from the action of steam and the quenching water which it comes in contact with during the quenching operations of the coke. The floor of the cab is of heat resisting material, while the compressor compartment floor is made up of steel plates riveted solid to the underframe. Openings are provided in these plates above the commutator end of the motors to permit inspection of the commutator and brushes.

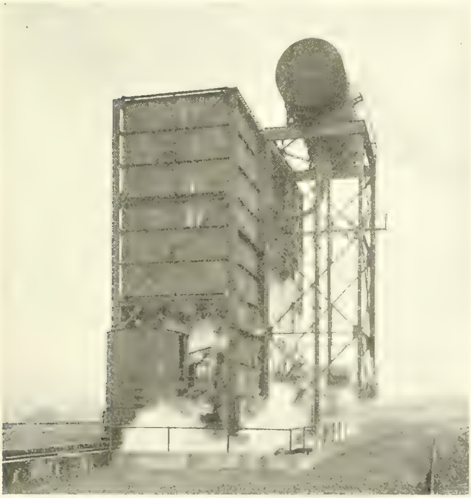

FIG. 7—QUENCHER CAR AND LOCOMOTIVE AT A QUENCHING TOWER

The control equipment and scheme of connections permits obtaining either hand control notch by notch on the master controller, or automatic acceleration up to any point on the master controller. This is particularly desirable where the class of labor, as it is here, requires that all possible protection be given the electrical equipment and that as little time be consumed as possible in accelerating. The close schedule of operations requires that every precaution be taken to prevent undue loss of time throughout the twenty-four hour, day after day operation. The control equipment includes also a potential relay so arranged that in case of failure of power it would be impossible for the locomotive to obtain power unless the motorman returns to the cab of the locomotive and re-establishes the control circuits after power comes on again. No main circuit equipment is in the operator's compartment; this all being in the compressor compartment of the cab. In addition to the protection afforded by the heavy plate construction of the cab, all control apparatus is enclosed in dust-proof cases.

COKE LOADING LOCOMOTIVES

Upon leaving the coke wharf, the coke is conveyed to a screening tower, from which it is loaded onto cars for shipment. A number of methods are employed in loading these cars and moving the cars under the loading chutes of the screening stations. A more recent and economical means employed at one large by-product plant consists of using electric locomotives, which can be controlled from the screening stations. The cars can be spotted under the coke chutes at will, without time consumed in signaling to an engine crew in the locomotive cab. Short and accurate movements of the train are obtained in either direction and this permits advantages which cannot be obtained with other systems in handling the cars during load, in that less coke is spilled, no time is lost due to signaling, the cars are more evenly loaded, resulting in greater capacity, and less labor is required, aside from the increased shipments of coke.

These locomotives, one of which is shown in Fig. 9, weigh 36 tons and are equipped with two 75 hp motors geared by double reduction to 33 inch driving wheels. They are normally supplied with power from two 250 volt third rails, located one on each side of the track, but are also provided with a 110 cell storage battery for operating outside of the third rail zone. This battery normally floats on the line, automatically receiving charge whenever the locomotive is operating from the third rails. The cells are normally connected in series, but the two halves of the battery can be connected in parallel for a gassing charge when desired.

The control equipment is of the standard electro-pneumatic type, providing for series-parallel control of the motors and having seven accelerating and two running positions. Operation from the locomotive is by the usual drum type of master controller. Remote control is accomplished through a control rail located directly under one power rail, to which contact is made with a current collector of the over-running type. This control rail and contactor furnish the only electrical connection between the locomotive and the control tower at the loading chutes, and carry only small currents.

Remote control is accomplished by energizing this control rail to a positive or negative potential depending upon whether forward or reverse operation of the locomotive is desired.* The potential on the control rail

[illegible] THE [illegible] CAR ONTO THE COKE WHARF
After it has been quenched at the quenching tower.

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*For details of this control scheme see article by the author on "Remotely Controlled Electric Locomotives" in the JOURNAL for Feb. 1920, p. 49.

operates relays which automatically throw off the air brakes and accelerate the locomotive in the desired direction to a speed corresponding to the third resistor step with the motors in series, giving a speed of approximately 0.5 miles per hour. Disconnecting the source of potential from the control rail returns the electropneumatic switches on the locomotive to the off position and sets the brakes.

The usual operation consists in the motorman taking the locomotive to the empty car storage track and hauling eight empty cars to the loading chutes at the screening station. The motorman then closes a changeover switch which provides suitable control connections to allow the locomotive to be operated from the tower. The locomotive is then under the control of the operator in the screening station, who moves the train slowly forward or back as the occasion may require, in order to secure evenly and completely loaded cars. There are two operators on the screening station, each located in a cab, midway between two tracks, and in addition to controlling all conveyors and screen equipment of one-half the screening station, each controls two locomotives at a time.

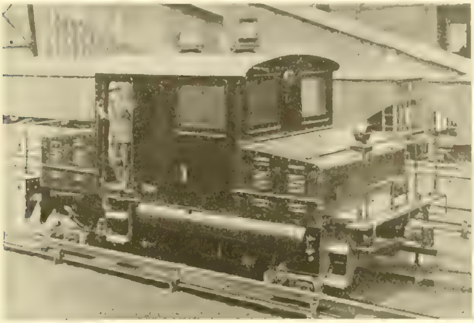
FIG. 9—TOWER CONTROLLED COKE LOADING LOCOMOTIVE

After the cars have been fully loaded, with 70 tons to each car, the motorman returns to the locomotive and hauls the train to the classification yards, after which he returns for another train of empties. Only two men are required to handle the shifting for the entire station, as the motorman does not need to be on the locomotive while it is being operated from the tower, and can be hauling one train out while another is being loaded.

The locomotives are equipped for multiple control from any of the locomotive cabs or from the tower. One of the big advantages of this type of equipment is the size of trains which can be handled, as with steam locomotives it is practically impossible to load more than three cars at a time, because the steam arising from the hot coke makes it impossible to signal the engineer from the loaders cab at any great distance. With a steam engine, an engineer and fireman are required and, because of the shorter trains, at least two crews would be necessary for each loading track. During the loading period there is so little for the crew to do that it is rather demoralizing. With the steam engine operation, it is frequently necessary to signal several times to get the engineer's attention, and the movements, when made, are often very erratic.

This system of remote control of locomotives has been highly successful in operation and should have a wide application wherever quick and accurate spotting of cars in a train is essential.

SUMMARY

Locomotives of the above classes have, in the modern steel plants and allied industries, more than proven their superiority from the standpoint of reliability and lower maintenance costs. They have been operated with greater safety than other types, have eliminated the smoke nuisance, and made working conditions better, all of which adds to production. The range of application of the electric locomotive in the various industries is practically without a limit, not only in supplanting other types of locomotives but in superseding various systems of haulage employing stationary machines as the source of power. The flexibility of the electric locomotive makes it able to meet successfully and economically varying service and emergency conditions.

Automatic Regulation of Electric Arc Furnaces

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PRACTICALLY all electric arc furnaces of large capacity are operated by alternating current. As three-phase power distribution is most common, and most economical, large furnaces are usually designed to utilize this power. Three-phase furnaces have two or three electrodes. Single-phase furnaces are provided either with two electrodes, as in the case of the single-phase steel furnace, or with one electrode, as in the case of many ferro-alloy furnaces. In the latter case, the hearth forms the other terminal. There are a few two-phase installations, employing four electrodes, in which case the three-phase power supply is converted into two-phase, either by a Scott-connected bank of transformers or by means of a motor-generator set.

REGULATING DEVICES

Several methods have been utilized to vary the constants of the circuit to comply with the demands of the furnace. The resistance of the line may be varied by means of a rheostat, or the reactance may be adjusted by a step inductance. The resistance method is out of the question, except for very small installations, due the amount of power wasted, and the step-by-step reactance variation is objectionable on account of the low power-factor introduced. Induction feeder and step-by-step regulators to handle the powers and voltages on the high-voltage side are expensive and cumbersome. The most logical as well as the simplest means of controlling the impedance of the circuit is found in adjusting the length of the arc by moving the electrodes themselves.

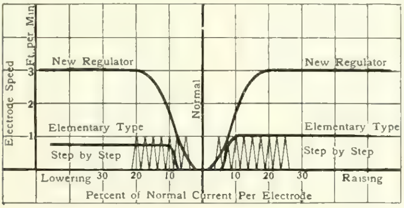

FIG. 1—CHARACTERISTIC CURVES OF DIFFERENT TYPES OF REGULATORS

ELECTRODE REGULATORS

When the electric arc furnace was first tried out on a commercial basis for melting metals, it was customary to control the feeding of the electrodes by hand. At that time, furnaces were comparatively small, and there was generally sufficient impedance in series with the furnace load to prevent dangerous surges of current incident to poor regulation. Also, the rates paid both for power and for labor were much more moderate than at present and the economic aspect of such a method was not serious. Today, however, with furnaces using so much power that one installation may consume an appreciable part of the total output of the average central station, and with the present rates being paid for labor, the automatic control of the arc becomes very important from the economic standpoint.

The art of electrometallurgy has attained such a stage that products are now being turned out of the electric furnace which were heretofore considered impossible of manufacture. The ability of the metallurgist to reproduce results, depends on his ability to control the conditions within the furnace. It is practically impossible with hand control to maintain as constant conditions in the furnace as with the automatic regulator.

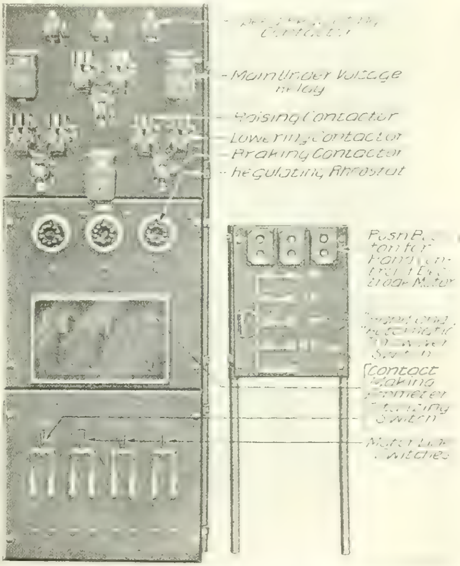

FIG. 2—ELEMENTARY CURRENT REGULATOR FOR THREE-ELECTRODE, THREE-PHASE FURNACE

The development of the arc lamp uncovered some of the problems incident to the automatic control of the electrodes between which the arc takes place. For an arc lamp to be successful, it was realized that some method must be devised that would automatically feed the electrodes toward each other as their ends vaporized. The regulation of the arc in the electric furnace is based on the same general principle, but presents a different problem in many respects. In the arc lamp, the parts are small and light in weight. The controlling mechanism, therefore, can be direct acting, and can control the position of the electrodes without intervening machinery. The mechanism of the electric furnace, on the other hand, is heavy, and unless an unwarranted amount of power is expended, intervening steps must be interposed between the controlling device and the motive power which operates the electrodes. This introduces both mechanical inertia and time lag between the abnormal condition in the furnace and the corrective influence of the regulating device.

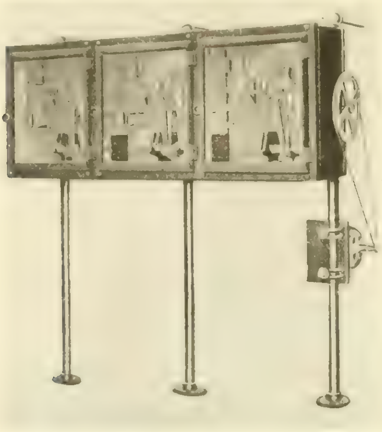

FIG. 3—STEP BY STEP REGULATOR

Electric arc furnaces are commonly provided with 230 volt direct-current motors for operating electrodes. The regulator controlling the furnace by means of the electrodes must therefore operate these motors.

ELEMENTARY REGULATORS

The elementary form of regulator consists of a control element, which is usually a contact making ammeter, voltmeter or wattmeter, connected to the circuit supplying power to the furnace. It is provided with two sets of contacts, one pair closing when the quantity being regulated is above normal and the other closing when the quantity is below normal. When the current is normal, both contacts are open. Each pair of contacts operates its own contactor switch, which in turn operates the electrode motor, either in a lowering or raising direction.

Such an elementary device is limited in its application, as will be appreciated when an examination is made of its operation. Assume that the furnace is drawing normal current. Both contacts on the control element will be open and the motors will be at rest. A change in the furnace conditions will close one of the contacts, which will operate the corresponding motor in a direction to compensate for the change. As the motor adjusts the electrode, the regulated quantity will approach normal again and when it reaches its normal value, the control element will disconnect the motor from the line and apply dynamic braking. Due to the inertia of the moving parts, however, the motors will drift somewhat, and if a fairly high electrode speed is used, the electrodes will over-travel a sufficient amount to change the regulated quantity to the opposite side of normal. Also, the inductance of the circuit will cause the current to rise somewhat after the element has broken contact. This will result in the motor being reversed and the electrode moved in the opposite direction.

The above tendency of a regulating system to oscillate is known as hunting and may be either a perpetual condition, after once being started or, if the amplitude of each surge is less than the preceding one, the system will eventually come to rest. In an elementary device, hunting is overcome by making the position of the control element lever dependent on the quantity being regulated and by separating the contacts far enough that the contact for running the motors in one direction does not close before the motors have stopped running in the opposite direction. Low electrode speed is also utilized to get away from this difficulty.

A type of regulator which obviates the hunting difficulty to a large extent has been in use for a number of years and is giving very good satisfaction. Instead of operating the electrode motors continuously, it applies current to them in a series of impulses. That is, when the quantity being regulated deviates from its normal value the electrodes are moved in a series of steps. If the change in the regulated quantity per step is smaller than the value necessary to cause the controlling device to reverse the motor, the regulator will not hunt. Such a regulator is known as the step-by-step type, due to its method of operation.

For a number of years, these two were the only types of regulators available for electric arc furnaces. When intelligently applied and used, both give very good satisfaction, as is borne out by the large number now in use.

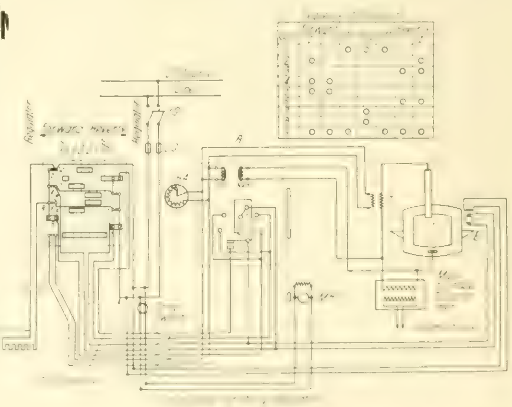

FIG. 4—CONNECTIONS OF STEP BY STEP REGULATOR

Recently a new type of regulator has been developed, which is a combination of the other two types.

A consideration of those described above will disclose that neither of the control elements is sensitive to the amount by which the regulated quantity differs from its normal value. When the quantity is being returned to normal, the electrodes are moving at a determined speed, which is constant and which bears no relation to the amount of the deviation from the normal value of the regulated quantity. In the new type of regulator, the motor speed bears a definite relation to the value of the regulated quantity. For instance, if the furnace draws a given percentage more current than normal, the motors will run at a given speed and as the current approaches normal, the motor speed will decrease and the electrodes will gradually be brought to rest. A deviation of more than 20 to 25 percent will cause the motor to run at its maximum speed until this 20 or 25 percent is reached, at which time the speed reduction will begin. Fig. 1 illustrates the approximate difference in the speed curves of the three types and shows how the new type of regulator brings the motors to a gradual stop.

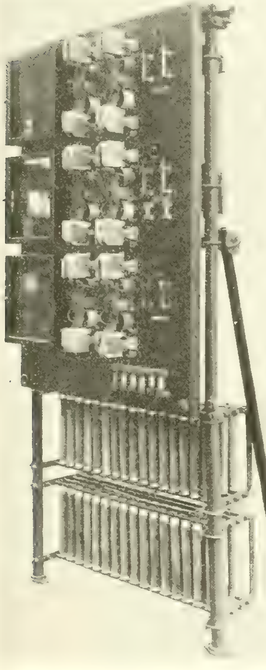
FIG. 5 REGULATOR PANEL

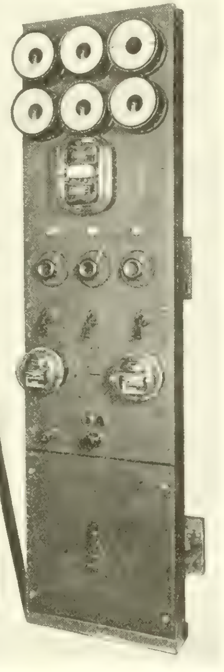
FIG. 6 SWITCHING AND METER PANEL

REGULATED QUANTITIES

A furnace regulator may be devised to maintain any one of three quantities constant; viz., the current in each electrode, the voltage across each electrode or the total wattage input into the furnace. There are also combinations of these three.

Current control is used in two of the types of regulators on the market at the present time for steel furnaces. Such regulators seem to be satisfactory in this field. They are most readily adapted to three-phase furnaces or to single-phase, single-electrode furnaces. They cannot be applied to single-phase, two-electrode furnaces, as the regulator is not sensitive to differences in the lengths of the two arcs. This would make for uneven heating and one electrode might even be submerged in the steel which, of course, is extremely undesirable. Also, it is impossible to use a simple current control on a two-phase, four-electrode furnace unless the two-phase is obtained from a three-phase system Scott connected. As far as the writer is aware, there are no furnace regulators depending solely upon the voltage across the arc for their operation.

As stated above, the simple current control is not applicable to two-phase furnaces, nor to single-phase, two-electrode furnaces. One method of controlling the current in a single-phase, two-electrode furnace is to control but one electrode by current and to control the other by means of a contact making differential voltmeter, one coil being energized by the voltage across one of the arcs and the other being connected across the other arc. The lengths of the two arcs are thus maintained equal.

The new type of regulator mentioned above utilizes both the current in each electrode and the voltage of each phase to neutral, on the same control element. The pull of the current coil opposes that of the voltage coil, and thus when these two pulls are equal for a given phase, the electrode operating motors remain at rest. It is evident that this new type of regulator is applicable to any furnace, because the regulator forces a balance of all arc voltages for balanced electrode currents.

In a simple type of current regulator, any interruption of the alternating current to the furnace while under automatic regulation, will result in lowering the electrodes into the bath. Cut-outs operated by the alternating voltage must therefore be placed in the circuits to the electrode motors. On the new type of regulator, these cut-outs are unnecessary, because the beam of the control element is returned to its normal position by means of springs as soon as both the current and voltage coils are de-energized.

In the steel industry particularly, it is highly undesirable that the carbon or graphite electrodes enter the steel bath. When using three-phase power, or when using single-phase with a two electrode furnace, one electrode may accidently be run into the bath before the current flow is allowed to start by lowering one of the other electrodes. With the new regulator, each electrode is independent and as soon as one electrode strikes the slag, the voltage across the voltage coil is reduced to zero and the descent of the electrode ceases.

A watt control regulator has been used in a few isolated cases on three-phase steel furnaces and on some single-phase furnaces. When controlling a three-electrode, three-phase furnace for constant wattage input, obviously the same difficulty is encountered as is found in trying to control a two-electrode single-phase furnace by current alone. In other words, an attempt is being made to regulate the same quantity by more than one device. In addition to a pure watt control, therefore, the voltage across each arc must be controlled to maintain the arcs of equal length.

TYPES OF REGULATORS

One type of simple current-control regulator is shown in Fig. 2. In this particular type, means are provided for obtaining higher speed of the electrodes under hand control, thus facilitating raising the electrodes out of the bath when it is desired to work with the charge. Another feature is the use of more resistance in the motor circuit while lowering the electrode, than while raising it. This gives a higher raising than lowering speed.

Fig. 3 illustrates a typical regulator of the step-by-step type. It is actuated by current alone, and is thus limited in its application as explained above. The type is familiar to all furnace men and a detailed description is therefore unnecessary. Fig. 4 shows the wiring diagram.

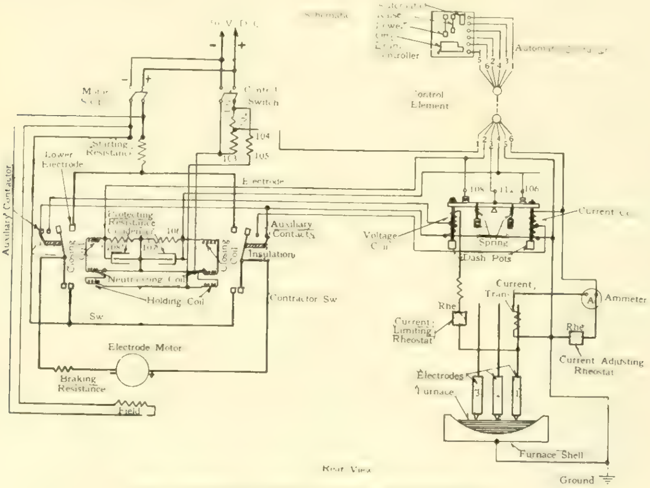

FIG. 7—WIRING DIAGRAM OF FURNACE REGULATOR

The new type of regulator discussed above is shown in Fig. 5. Fig. 7, is a schematic wiring diagram of this regulator, and Fig. 8 shows the connections to the control element for one of the electrodes. The two sets of contacts on the lever control the electrode operating motors through the medium of magnetically operated contactor switches, which are mounted on the regulator panel.

Assuming that the furnace is about to be started up, neither of the solenoids on the main control element, *V* or *A*, will be energized until the main circuit breaker on the high-voltage side of the furnace transformer is closed. Under these conditions, the two springs, *1* and *2* will hold the lever in a horizontal position, maintaining contacts *3* and *4* open. On closing the main circuit breaker, a potential will be immediately created between each electrode and the shell of the furnace. Voltage coil *V* is now energized and pulls up on its core, closing contact *3*, and operating the electrode motor in a direction to lower the electrode continuously and at full speed until it makes contact with the bath. As the voltage coil is connected between the electrode and the furnace shell, its current will be shunted and it will become de-energized the instant the electrode makes contact with the steel, thus allowing the lever of the main control element to return to its horizontal position and open the motor circuit. As no alternating current can exist in any electrode until two or more are in contact with the bath, current coil *A* will not be energized until one of the other electrodes is lowered sufficiently far to strike the bath. As soon as the circuit is completed, current coil *A* becomes energized. Contact 4 is thereby closed and causes the electrode motor to raise the electrode, thus drawing an arc to the bath. The sequence of operations is similar for the other phases. The motor continues to raise the electrode until the voltage between the arc and neutral increases and the current in the electrode decreases to such an extent that the pull of coil *A* is equivalent to that of coil *V*. The lever will then assume a horizontal position, opening the motor circuit. Any disturbance of the equilibrium between the pull of coils *A* and *B*, due to variations in the arc, will cause either contact *3* or *4* to close, thus operating the electrode motor in a direction to compensate for the disturbance.

Current adjusting rheostat *C* is connected across the current transformer and by changing its position the value of the current per phase for a given current in the current coil of the current element can be altered at will within the limits of the apparatus. This current can be varied from its normal value to approximately 20 percent of the normal value.

Auxiliary contacts *5* and *6* are mechanically attached to but insulated from the magnetically operated contactor switches, which control the electrode motors. Contact *5* closes when the *lower* contactor switch closes, and contact *6* closes when the *raise* contactor switch operates. These contacts shunt respectively, a part of coils *V* and *A*. Therefore, after the lever has been moved in a direction to operate the *raise* contactor, the auxiliary contacts attached to this switch will close, thus shunting a part of coil *A* and tending to restore the lever to its horizontal position. If the change in pull is sufficient to allow the lever to operate, its contacts will separate and allow the contactor switch to open. If, during the time that the contactor switch was closed, the motor has not moved the electrode a sufficient distance to adjust the current to the value for which the regulator is set, the pull of coil *A* will still overbalance that of coil *B* and the *raise* contactor switch will again close contacts *4*. A vibrating condition will thus be set up between the control element and the contactor switch. If the current per phase is more than approximately 15 percent either side of its normal value, the change in pull on short-circuiting a part of the winding on coil *A* by the auxiliary contacts, will be insufficient to allow the core to drop. The contactor switch will, therefore, remain closed and the electrode motor will operate continuously in a direction to compensate for the abnormal current. As soon as the current reaches approximately 15 percent of normal, the change in the pull on the solenoid *A*, when the auxiliary contacts *5* close, is sufficient to allow the core to drop out and to bring the lever to its horizontal position. Between this 15 percent point and the normal value of the current, the regulator assumes a vibrating condition and the motors are subjected to a series of impulses, the average time the motor is connected to the circuit being a function of the amount the alternating current deviates at any particular instant from its normal value. There are two distinct stages, therefore, in the operation of the regulator, one being the continuous running stage, and the other the vibrating stage. The vibrating feature permits the motors to operate at high speed until the current in the electrode has been brought back to within 15 percent of normal (approximately) when the speed is gradually reduced to zero. High speed and freedom from over-shooting are thus obtained.

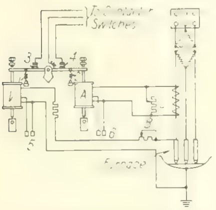

FIG. 8—SCHEMATIC DIAGRAM OF SWITCH GROUP

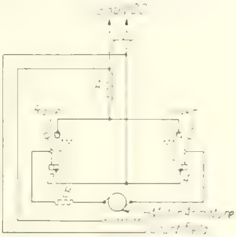

FIG. 9—SCHEMATIC DIAGRAM OF CONTROL ELEMENT

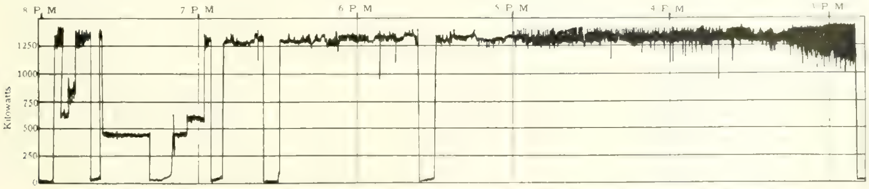

FIG. 10—POWER CONSUMPTION CURVE OF SIX TON HEROULT FURNACE WITH NEW TYPE OF REGULATOR

A schematic diagram of one electrode motor circuit is shown in Fig. 9. *C* and *D* are two double acting contactor switches which start, reverse, and apply dynamic braking to the electrode motor. *A* is a resistance in the supply circuit which acts as a starting resistance, and *B* is a smaller resistance which acts as a braking resistance when the motor is brought to a stop. The shunt field is permanently connected to the direct-current supply.

If the current in one electrode has fallen below its normal value, the main control element will close switch *D*, thus connecting the motor to the line through resistance *A* and *B*. When the alternating current has reached its normal value, the control element lever will assume a horizontal position and switch *D* will open contact *3* and close contact *4*. Contact *2* has been closed during this operation and the motor armature is now short-circuited through resistance *B*, thus applying dynamic braking to the armature. It is to these contactor switches that the auxiliary contacts are mechanically attached. Resistance *A* and *B*, Fig. 5, are adjustable by taps and, therefore, are adaptable to any motor between 2 and 5 hp, 230 volts. The taps also permit adjustment to take care of any conditions that may be encountered.

It will be noted from Fig. 4 that the regulator panel mounts the contactor switches and control elements, as well as fuses, knife switches, etc. All of the control equipment which the melting crew are required to handle is mounted on a separate panel. The regulator panel can, therefore, be set-up in some more protected place than the furnace room, thus protecting it from dust and dirt.

A connection to the shell of the furnace is required to supply excitation to the voltage coil. In basic lined furnaces it is found that the lining is sufficiently conductive to operate the voltage coil without inserting metallic electrodes. With an acid lined furnace it is necessary to use metallic electrodes projecting through the bottom. Small rods of steel or some high melting alloy, if properly installed, have no detrimental effect on the lining.

Some of the features claimed for the new regulator are a high electrode speed and freedom from hunting. The high electrode speed (36 inches per minute under automatic regulation) permits the regulator to extricate the electrodes from the steel as the scrap caves in. An interesting feature regarding the electrode speed is that during the vibrating interval of regulation (the zone through which the alternating current is 15 percent above or below normal), the speed is greater while lowering than when raising. The number of times the arc is broken on melting down cold scrap is reduced in this way. The stability of the regulator permits it to be cut in on starting a cold charge, after which it requires practically no attention.

A typical curve taken with a direct acting graphic wattmeter on a six ton Heroult furnace melting cold scrap and making alloy steels is shown in Fig. 10. No special care was used in charging, and the regulator was cut in as soon as the furnace was started. The short time in which the furnace settled down is interesting and the absence of high current peaks is also noteworthy. A high speed regulator would be expected to keep down demand peaks and the curve seems to justify this expectation.

Although this new regulator for electric arc furnaces has not been on the market for any great length of time, it has been very successful. Furnace operators who have used it like it, and the installations which have been made have given satisfaction.

Oil Circuit Breaker Arrangements and Switching Schemes for Steel Mills

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THE RAPID growth in the use of electric power in the steel mills has brought about a condition in the switching equipment that requires considerable study on the part of electrical engineers to provide adequate protection for the electrical machinery. Most of the switching equipment installed but a few years is now mechanically inadequate for the service required. This condition, in general, was not brought on by misapplication of circuit breakers, nor wholly by the lack of foresight. Perhaps, some of it could have been foreseen and proper care taken to provide for future growth and extension, but it is doubtful if the expense would have been justified at that time. Mainly, this condition was brought on by the recent unprecedented requirements for steel, necessitating extensions and additions, to the plants. There has also been a decided tendency, growing in volume each year, to electrify the mills. This, perhaps, has been the largest single factor in increasing the electric power consumption in the steel industry.

A few years ago, a ten or fifteen thousand kv-a. power plant was considered rather large for a steel mill. At present the opposite is true, the range now extending from these figures to 100,000 kv-a., and provision has been made in some plants for 200,000 kv-a. Also it is not unusual, and the tendency is growing, for the larger companies that have a number of plants in the same vicinity, to tie their power systems together. Fig. 2 shows a schematic diagram of one of the large company's interconnected power plants. The smaller companies are connecting with the local central station companie's lines. Fig. 1 shows a schematic diagram of one of the small companies which has tied to a large local power company's system. Thus in most cases, by one of the above methods, the steel mills have provided themselves with a large source of power, thereby bringing about conditions which must be met if the electrical machinery is to be protected properly and continuity of service guaranteed.

Several methods have been developed for applying additional switching equipment or remodeling the old in some manner to provide protection. All have met with more or less success depending upon the degree of protection desired, and the investment which can be provided for protection.

The natural remedy would appear to be the removal of the antiquated equipment and substitution of new circuit breakers having sufficient interrupting capacity to take care of any abnormal condition. This subject of interrupting ability which depends on the mechanical features of circuit breakers is too large to permit of lengthy discussion in this article.* It must be borne in mind that the mechanical design of the circuit breaker is of great importance. It is because of insufficient mechanical strength that most circuit breakers become too small for the service when the generating capacity of the power plant is increased. Their current carrying capacity and voltage rating may be sufficient, but the design of the tank, frame, contacts and other mechanical parts is not large enough to withstand the strain set up by a short-circuit current which may be obtained from the increased generator capacity of the plant. However, the substitution of large interrupting capacity breakers is not always practical and is usually expensive except in new installations. For these reasons it is natural to turn to some method that will permit the use of existing equipment with as few changes in the layout as possible, and the least disturbance to the various circuits.

GROUP CIRCUIT BREAKER SCHEME

This method of arranging circuit breakers to give protection for abnormal conditions that may occur on any circuit, as the name implies, is employed to give protection to a group of feeders that do not have individual circuit breakers of sufficient interrupting capacity to open a short-circuit which may occur on any one of the feeders. The scheme is very simple, comparatively easy to install, and requires very little additional equipment. It consists, principally, of a large interrupting capacity circuit breaker of sufficient current rating for the combined currents of all feeders to be protected. This circuit breaker, usually designated as the "main" or "group" breaker is installed ahead of the feeder breakers. It may be either manually operated or electrically operated. Two overload relays and one direct acting relay are installed on each of the individual feeder breakers. In addition, indicating lamps may be installed on the feeder to indicate open and closed position of the breaker, and a push switch for hand tripping.

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*See article on "The Design and Selection of Oil Circuit Breakers" by J. W. Mahoney in the JOURNAL for Nov., 1918, p. 462; and on "Oil Circuit Breakers and Their Application" by J. B. MacNeill in the JOURNAL for Aug. and Nov., 1916, pp 364 and 547.

Two main conditions must be met before the scheme can be employed. First, the feeder breaker must have sufficient carrying capacity for a period of time, such as five seconds, to take care of the current developed on a short-circuit; and second, the group breaker must have sufficient interrupting capacity to open the short-circuit successfully. Usually, it is desired that the group breaker be arranged for instantaneous trip. This gives better protection but requires a larger interrupting capacity. Two methods may be employed to trip the group breaker, namely:—direct trip by means of alternating-current trip coils energized from a current transformer, as shown in Fig. 3; and shunt trip by having the trip coils energized from some direct-current source as shown in Fig. 4. For manually operated breakers, usually the direct-current source for tripping is a low-voltage storage battery ranging from 6 to 15 volts and for electrically operated breakers the standard 125 or 250 volt control circuit is used. It is not necessary that both methods of trip be employed, although in some cases serious consideration may be given toward providing them, as they give two independent means of tripping. This is desirable for the scheme, inasmuch as it gives more reliability in case of failure of one or the other tripping source.

The feeder breakers have only one means of tripping, the shunt trip direct-current coils. If the breakers are manually operated these coils may be the five ampere alternating-current trip coils already in the breakers, the two tied in series being suitable for direct-current 6 to 12 volt battery service or a single direct-current shunt trip coil for 6 to 12 volt service. If the breakers are electrically operated the standard 125 volt or 250 volt shunt trip coils are used. In either case, they are energized from the same source as the group breaker coils. In addition to the trip coils, the feeder breakers, as previously mentioned, are equipped with overload induction type relays and a two coil direct acting relay that latches in the open position. This latch is equipped with a magnetic reset coil for releasing. The main coils of this direct acting relay are energized from the current transformers of the feeder circuit and connected in series with the coils of the induction type relay. A certain definite minimum number of ampere turns are required to operate the direct acting relay. Therefore its coils are designed with such a number of turns as to give this minimum required number of ampere turns at a point considerably above the usual overload rating of the feeder, but within the range of the short-circuit interrupting capacity of the feeder breaker. This will permit the feeder breaker to take care of a short-circuit whose magnitude is not beyond its interrupting capacity.

To determine the current necessary to give the required ampere-turns for any coil in the direct-acting relay, it is best to assume an interrupting capacity of about 80 percent of the rating of the feeder breaker. This is safe and permits of some range in the use of the feeder breaker other than for ordinary overload. For example, assume that the feeder breaker has an interrupting capacity of 6000 amperes at line voltage, and is used on a circuit having 300/5 ratio current transformer. The 80 percent value of 6000 is 4800.

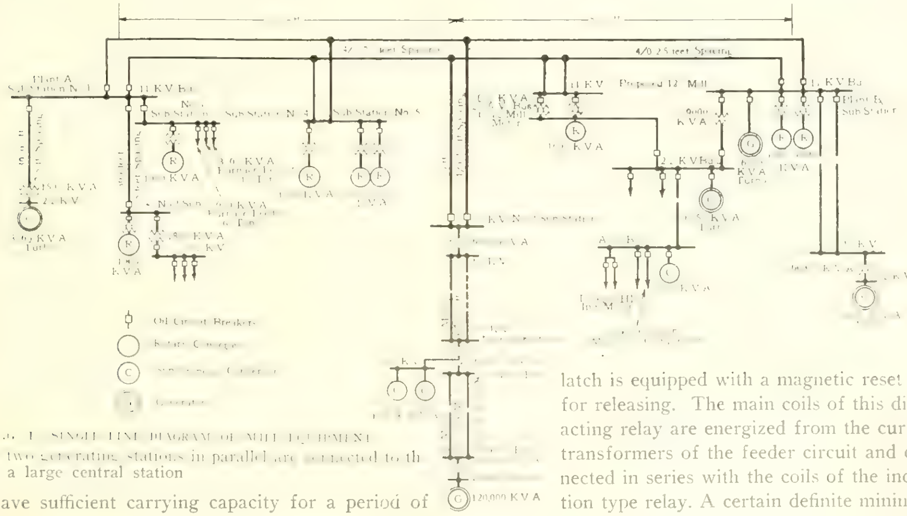
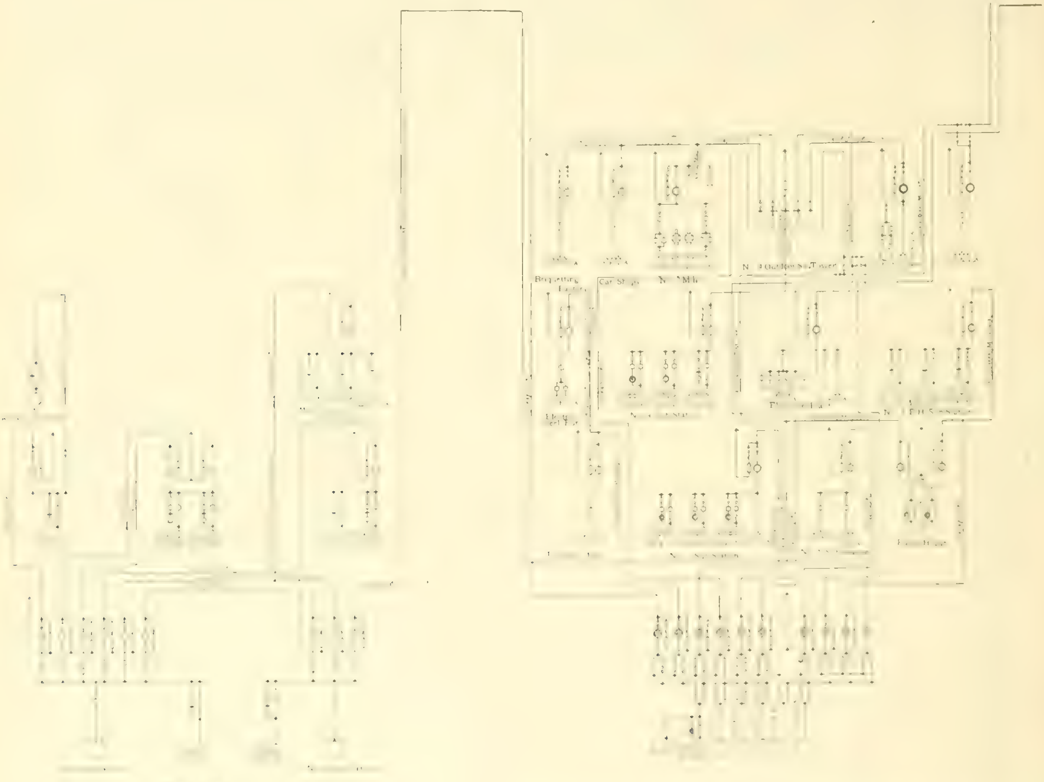


FIG. 1—SINGLE LINE DIAGRAM OF MILL EQUIPMENT

The two generating stations in parallel are connected to the lines of a large central station

This 4800 value represents the current point beyond which the breaker is not to open. Therefore, the secondary current, which actuates the direct acting relay coils, is the primary current divided by the ratio of the current transformer, giving 80 as the ampere value for the coil necessary to give the required ampere turns to cause the direct acting relay to operate and trip the group breaker. At any lower value the direct acting relay will not function. Therefore, the individual feeder breaker will be required to open any current value up to this point.



Plant No. 1 Plant No. 2

FIG. 2—SINGLE LINE SCHEMATIC DIAGRAM OF POWER PLANTS AND

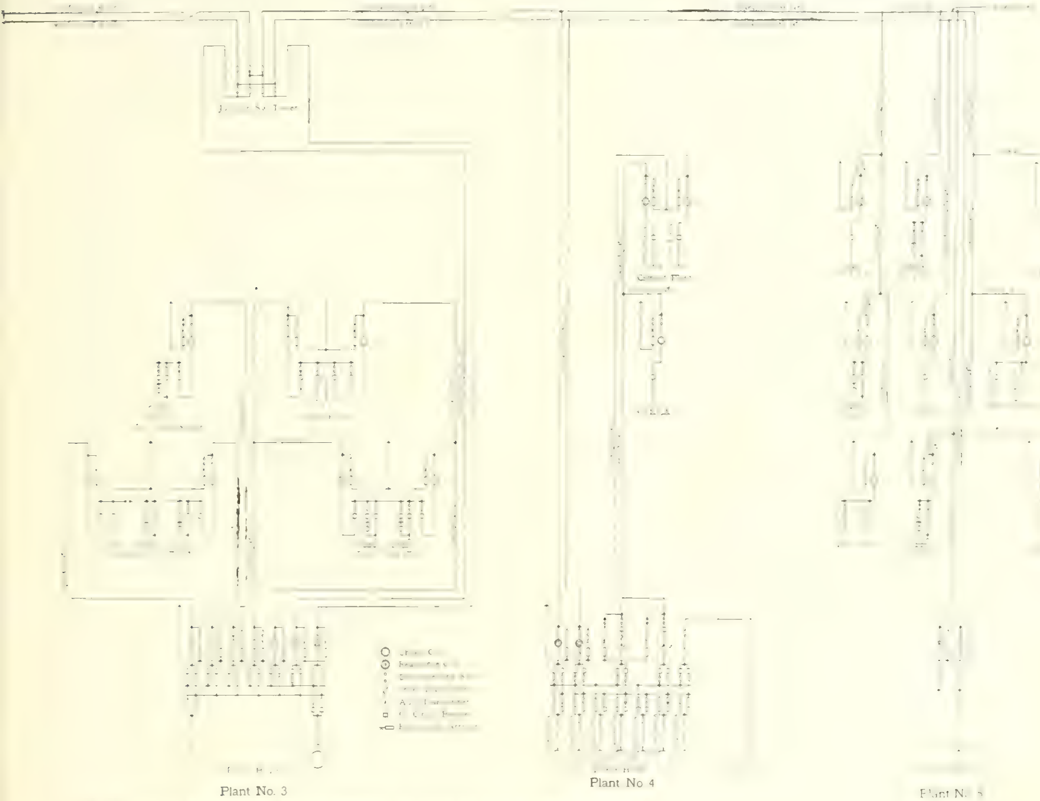
The actions of the scheme under ordinary overload and short-circuit conditions are briefly as follows:—

> 1. Under ordinary overload, the current developed in the [illegible] magnitude to give the required ampere turns to operate the direct acting relay, but will operate the induction type time limit overload relay, closing its contact, thus tripping the feeder breaker. The action in this case is the same as on any ordinary feeder protected by time limit overload relays. The direct acting relay has no effect or function to perform.
>
> 2. When a [illegible] on the feeder, the current rises instantly to a value that will produce the required ampere turns to operate the direct-acting relay.

The time limit overload relay, having a definite time setting, will not act before the direct acting relay operates and opens a pair of contacts which cut out the trip circuit of the feeder overload relay. This makes the feeder breaker non-automatic. At the same time a second set of contacts on the direct acting relay closes, energizing the trip coil of the group breaker. The group breaker, therefore, opens the short-circuit. A third set of contacts on the direct-acting relay closes at the same time as the second set. These are connected in series with a set of auxiliary contacts on the group breaker which closes when the breaker opens. The closing of these contacts energize the trip coils of the particular feeder breaker in distress, thereby clearing the bus of the defective circuit. The feeder breaker is also equipped with an auxiliary switch that closes when the breaker opens. The closing of this auxiliary switch energizes the reset coil of the direct acting relay, releasing the latch and permitting the relay to reset itself in normal position for service. Fig. 5 indicates the necessary wiring for the above arrangement.

Due to voltage failure on the system under short-circuit conditions this scheme will not permit the use of a low-voltage coil on any feeder breaker. Where low-voltage protection is desired on a feeder, a low-voltage relay with a definite minimum time limit must be installed. The trip circuit of the low-voltage relay is connected in parallel with the trip circuit of the overload relay, so that on a short-circuit, the trip circuit is disconnected from the trip coil of feeder breakers by the operation of the direct acting relay.

It is not necessary to use a low-voltage relay on every feeder which is to be protected against voltage failure. A multicontact relay, with one low-voltage relay, is connected to the main bus, and the multicontact relay coil is connected to the low-voltage relay so that it is energized when the low-voltage relay acts. The various contacts on the multicontact relay are connected to the trip coils of the various feeders that require low-voltage protection, so that the closing of these contacts trip these breakers. Fig. 6 shows the method of connecting such a scheme.



MILL EQUIPMENT LOCATED IN FIVE SEPARATE MILLS OF ONE LARGE COMPANY

While the above group breaker scheme is the one most commonly used for steel mill application, the following refinement has certain advantages.

A Reclosing Feature permits the automatic reclosing of the group breaker when the particular feeder breaker under distress has been opened, clearing the system of the defective circuit. Fig. 5 shows in dotted lines the connections to provide this feature. It will be noted from the diagram that no elaborate wiring is necessary, the addition of the auxiliary relay with its connections and one auxiliary switch on the group breaker being all that is required. Naturally this scheme cannot be used unless the group breaker is electrically operated. The action of the scheme is as follows: The reclosing auxiliary relay is latched automatically in the open position when the group breaker closes. When a short-circuit occurs on any one of the feeders, the direct acting relay on this particular feeder acts, closing its contacts and tripping the group breaker. The feeder breaker on the defective circuit then trips out, the same as with the main scheme previously described, clearing the short-circuit. The coil operating the magnetic catch on the reclosing auxiliary relay is connected in parallel with the trip circuit. Therefore, it acts and releases the catch on the reclosing relay permitting the relay to close its contacts. When these contacts close, the closing coils of the group breaker are energized, thereby closing the breaker. At the same time the main coil of the reclosing relay is energized causing it to act and reset itself. A dashpot, time-element device is placed on the reclosing relay to give a delayed action sufficient to assure time for the group breaker to close. When the reclosing relay has operated and reset itself, normal condition is again restored. The advantages of this feature are obvious, where no synchronous apparatus is fed. It is hardly to be expected that the action of the group breaker in opening and reclosing will be rapid enough to keep synchronous apparatus from dropping out of step. Therefore, extra precaution must be taken to assure the tripping of circuits of this type. While this adds certain complications and necessitates additional wiring and removes some of its advantages, it does not necessarily mean that the scheme cannot be adapted to the use of plants having circuits controlling synchronous apparatus. This, however, has been the main reason for not adopting the reclosing feature of the scheme in the steel industry.

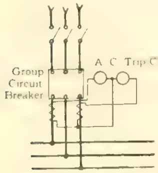


FIG. 3—ALTERNATING-CURRENT DIRECT TRIP FOR GROUP CIRCUIT BREAKERS

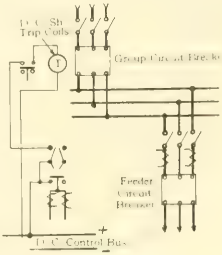


FIG. 4—DIRECT-CURRENT SHUNT TRIP FOR GROUP CIRCUIT BREAKERS

The group breaker scheme is not claimed to be the best protection in all cases. It is, however, claimed to be about the best protection obtainable with relays. Naturally relays are not infallible and they do require attention, therefore the scheme, as mentioned previously, will provide only reasonable protection but at a minimum cost and very little disturbance to the existing apparatus. If one wishes to go farther and provide still greater degrees of protection, combined with flexibility in the use of the switching apparatus, thereby gaining in the assurance of continuity of service, the auxiliary bus system is recommended as having proven itself efficient.

AUXILIARY BUS SYSTEM

This system provides for the use of such existing equipment as may be reasonably safe by installing a new system either adjacent to the present structure or in a separate switch house. The old and the new structure are tied together by means of a tie breaker. Fig. 7 shows a schematic diagram of an adjacent structure. As indicated in the diagram, a complete new structure is installed adjacent to the old structure. The old structure is used as the auxiliary and the new as the main operating bus. Therefore, all new and future circuits, as far as possible, are added to the new bus. The tie breaker is made quick acting, instantaneous, and has sufficient interrupting capacity to open any short-circuit that may occur, thereby clearing the auxiliary bus in case of trouble. The feeder breakers in the old structure are provided with induction-type time-limiting overload relays. This gives a delayed action, permitting the tie breaker to open first. The breakers in the new structure also have relay protection, and in addition have interrupting capacity sufficient to open any short-circuit. The application of the scheme is limited, however, to the ampere carrying capacity of the old breakers and to the mechanical strength of the old bus-bar supports.

Fig. 8 indicates the essential connections necessary for a separate bus structure located at some distance away from the present bus structure. The breakers in the new structure, as in the above scheme, are of sufficient capacity to interrupt a short-circuit. The tie line is provided with two breakers, one in each structure, all having overload protection by means of time limit relays.

The successful operation of the scheme depends upon the difference of time setting of the overload relay on the tie breakers, the relay on the tie breaker in the new structure having a shorter time setting than the relay on the breaker in the old structure. It is not necessary that the arrangement be made in this manner, but the use of a relay permits a smaller breaker for the tie on the old equipment structure end of the tie line. Usually this is desirable as the old structure is never intended to be added to, but all future additions will be made to the new structure. The tie line is to be used more as an emergency than a permanent transmitter of power between the two stations.

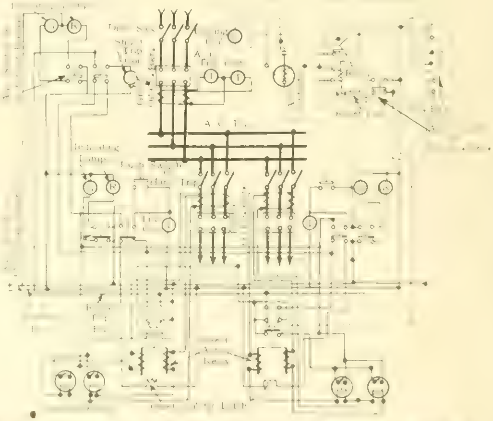


FIG. 5—GROUP CIRCUIT BREAKERS SCHEME TO PROTECT A GROUP OF FEEDER BREAKERS

The dotted portion of this diagram shows the necessary additional apparatus and connections for the automatic reclosing feature.

Both systems described above can be made a double bus arrangement. Fig. 9 shows a schematic diagram of the adjacent structure arranged for a double bus. Usually it is a very simple matter to install this new structure above, below or in the rear of the old structure. A feeder breaker of sufficient interrupting capacity is provided in the new structure for each feeder in the old structure. If space will not permit or the cost is too great to provide each feeder with a double breaker arrangement, they can be provided on only the important feeders. This, in most cases, will be sufficient. The two breakers are tied together through disconnecting switches, so that either may be used on the feeder. Usually it is desired to operate from the new structure through the new and larger breaker, using the old breaker and old structure, as far as possible, only for emergency. The current transformers on the feeders are relocated beyond the junction of the two breakers. Only one set of overload relays are necessary for the two breakers on each feeder. As indicated in Fig. 9, the relays are connected so as to trip either of the breakers that may be in service. It will be readily seen that the scheme has practically all the advantages of a double bus system, and is, therefore, preferable to the single bus. The application is limited, as in the case of the single bus scheme, by the normal and five second ampere carrying capacity of the old breakers and by the mechanical strength of the bus-bar supports in the old structure.

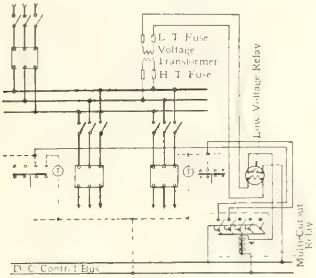


FIG. 6—LOW VOLTAGE PROTECTION ON THE GROUP CIRCUIT BREAKER ARRANGEMENT

Fig. 10 shows a single line diagram for a separate double bus structure located at some distance away from the present bus structure. The scheme is virtually the same as the single-bus, separate-structure scheme described above. The tie line is provided with four breakers, two in each structure. The two breakers in each of the structures are tied together through disconnecting switches. The transformers for operating the relays and meter are located beyond the junction connecting the two breakers. Two relays for each group of breakers are provided for the tie line and feeders. For continuity of service this scheme is preferable to any one of the similar schemes described above.

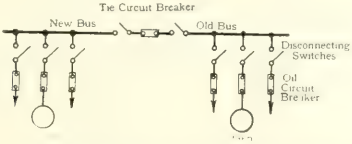


FIG. 7—SINGLE BUS, AUXILIARY BUS SYSTEM
With the old and new structures adjacent.

These schemes, as well as the group breaker systems, have their limitations. Quite frequently it is found advantageous to preserve the existing equipment without any remodeling or changing and install reactance coils.

REACTANCE COILS

The maximum initial rise in current above normal generator capacity of the power plant at any point on any alternating-current system during a short-circuit depends upon the total reactance of that part of the system up to the point at which the short-circuit occurs. This current gradually decreases as the elapsed time increases. This is shown very clearly from the curves in Fig. 11. Therefore, the short-circuit current developed at the bus, the usual location of the breakers, will depend upon the amount of reactance of each machine, plus the reactance in the leads. The standard turbogenerators being built under present day practice have from 8 to 12 percent reactance. Usually the switching equipment is so planned with respect to the machine that very little additional reactance is obtained in the leads. Perhaps one-half of one percent is the average reactance for leads. This amount, of course, depends entirely upon the number of leads required, their arrangement with respect to each other, the distance from generator to switch, and the voltage of the system. Usually, this lead reactance is treated as negligible, unless in exceptional cases a favorable arrangement can be made to utilize it. The dependable reactance, therefore, is the reactance of the machine alone.

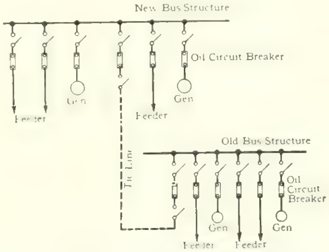


FIG. 8—SINGLE BUS, AUXILIARY BUS SYSTEM
With the new bus structure located at some distance away from the old structure.

The present day practice is to rate circuit breakers for ampere interrupting capacity and momentary ampere carrying capacity for a definite period of time, such as five seconds, at service voltage, in addition to the continuous ampere carrying capacity and maximum service voltage. The correct application of any circuit breaker demands that all five of the above breaker characteristics be borne in mind and their limits not exceeded. The amount of short-circuit current that the breaker will be called upon to open for a given kv-a. generator rating, as pointed out above and shown from the curves in Fig. 11, depends both upon the amount of reactance in the circuit and on the elapsed time from the instant of short-circuit. No oil circuit breaker can be built to open instantaneously. An appreciable amount of time must elapse in the operation of the trip coils, the releasing of the trigger and the travel of the main contacts. This time is usually about 0.20 to 0.25 of a second for the larger size of breakers.

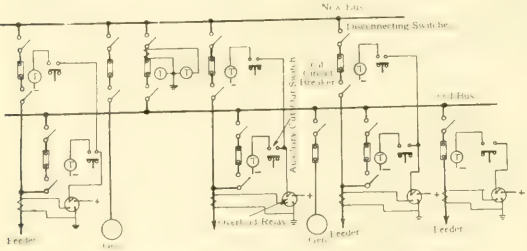


FIG. 9—DOUBLE BUS, AUXILIARY BUS SYSTEM
With the old and new structures adjacent.

It is obvious then, that the insertion of additional reactance will permit the use of circuit breakers having less interrupting capacity rating, than the generating capacity of the system on which they are used. In addition, the use of reactance coils reduces the mechanical strain on all parts of the system due to magnetic stress set up by the great rush of current under short-circuit conditions. In most installations that have been made a few years ago, the bus-bar and cable supports do not have sufficient mechanical strength to meet the increased stresses produced by present day conditions. Therefore reactance coils become of double importance wherever the capacity of the plant has outgrown the capacity of the switching equipment. Moreover, the use of reactance coils has an advantage over the group breaker system in that it eliminates the serious objection to opening the main circuit breaker instead of the individual feeder affected.

Fig. 12 shows some of the locations recommended for reactance coils. Location *A* is noticeably the most effective, as it protects service on all the other feeders and gives maximum protection to the switching equipment. The cost, however, may be prohibitive or space will not permit its use. Therefore location *B*, which protects a group of feeders will be the next best. The third choice would be to locate the reactors at *C*. However, each installation should be considered and the location selected that will afford maximum protection to both the apparatus and service. No hard and fast rule can be made to cover all cases. Quite frequently it is desired to hold the voltage up under short-circuit conditions on some important feeder, such as the exciter, station auxiliary, or pump feeder. In this case, location *D*, which is somewhat similar to *B*, becomes of greater importance by serving a double purpose.

Reactance coils, while reducing the current rise on short-circuit, thereby providing protection for the circuit breakers and reducing the mechanical strains on all parts of the system, do not eliminate trouble due to voltage surges, which may be of sufficient magnitude to puncture the insulation of the transformer or rotating machine. Eliminating this trouble requires that particular attention be paid to line material, arrangement, and location of lightning arrestors and choke coils, and the grounding of the neutral of the system.

GROUNDED NEUTRALS

Perhaps, no industry using a large amount of electric power is subject to more trouble from voltage surges than the steel mills. Primarily, this is due to arcing grounds. Fumes, dirt and dust, accumulating on the line, insulators and supports, weaken their insulation resistance, causing them to break down and arc over. As the arcing ground, due to capacitance and inductance, is oscillating, it produces a very high voltage, which may be many times the normal across an inductance in the circuit. Unless extra precautions are taken to provide means for cutting off the circuit on which it occurs, serious damage is liable to result to machines, somewhere on the system. This puncturing of machine windings or flashing over may occur on several machines simultaneously or successively, thereby tripping out switches on different parts of the system. If this occurs, there is no definite manner of determining quickly the faulty line and clearing the system of the trouble. The most effective means of curing this source of trouble is to ground the neutral of the system permanently either directly or through a grounding resistance. In addition, special care should be taken to provide all lines with insulators of sufficient voltage rating to provide ample factor of safety, and with proper choke coils and lightning arresters. The arresters should be so located with respect to the choke coils, that short and straight connections can be

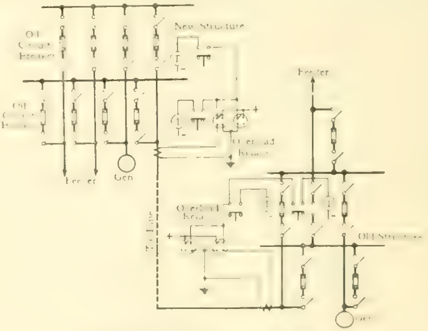


FIG. 10—DOUBLE BUS, AUXILIARY BUS SYSTEM
With the new bus structure located at some distance from the old structure.

made between the arrester and the line and between the arrester and ground.

Most of the steel companies have been reluctant about grounding the neutral of their system. They feel that for the commercial power companies, having a wide range of distribution and high transmission voltage, the grounded neutral is satisfactory. In their case, however, with small area of distribution, with limited number of lines and low-voltage distribution, they feel that very little additional protection will be gained. In small plants, perhaps, this is true. However, it is questionable, due to the very fact that these plants transmit at generator voltage direct into the machine without transformers, thereby losing the choking and isolating effect of the transformer windings. With the larger companies having several plants tied together, there is no question but that the grounded neutral will relieve them of considerable trouble and add to the reliability of service.

In the case of one of the large steel companies where several plants are tied together, experience has shown that a break down or arcing over at one point causes simultaneous or successive break downs at other points. For example, a generator broke down at one of these plants and approximately at the same time a motor in another plant a mile away broke down. These disturbances became so frequent and caused such serious delays that a grounded neutral was recommended as the best means of relieving the system of these disturbances. While these recommendations were not at the time carried out, they are now arranging for grounding the neutral in one of the plants.

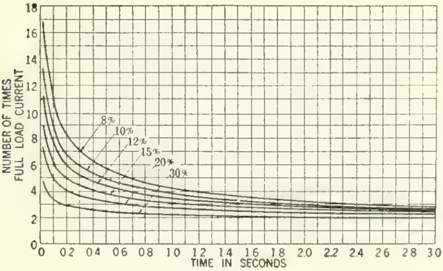


FIG. 11—THREE-PHASE SHORT-CIRCUIT CHARACTERISTICS
Based on total kv-a rating of synchronous machines.
Initial full load at eighty percent power-factor assumed.
Initial full load at eighty percent power-factor assumed.

It is true that grounding the neutral will not prevent all the first cases of line failure, such as insulator break down or punctured windings in the apparatus, but subsequent resultant break downs seldom if ever occur. This is due to the fact that a ground on a grounded neutral system produces a dead short-circuit or a "power" arc. In either case no oscilllatory surges can exist to produce abnormal potentials at other parts of the system. Therefore, with the elimination of subsequent resultant break downs, practically all the trouble on a grounded neutral system will be confined to one point, with the current in the short-circuit flowing over a definite path. This becomes of double importance by providing definite knowledge for automatically selecting the feeder in distress and making possible selective action of the relays.

Usually one neutral ground for a system is sufficient, this being generally at the generating station.

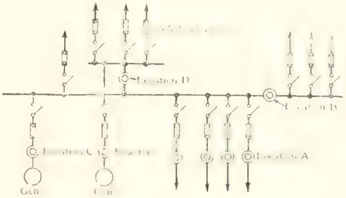


FIG. 12—LOCATION OF CHOKE COILS
For various degrees of protection.

However, in the case of several plants tied together, it may be desired to ground each power house on the system, as there will be times when the power houses will operate separately. With this separate grounding of each power house there is liable to be an interchange of current between ground which may interfere with the telephone circuits. If this is found to be the case, only one power house, centrally located, should be grounded at any one time.

The best operating condition in grounding a power house is to run a neutral bus. The neutral of any generator can be connected to this bus through disconnecting switches and single pole breakers. This bus is then grounded. By the manipulation of the switches any one of the machines may be grounded, making a more satisfactory operating condition than if only one machine for the whole station was selected for grounding. Fig. 13 shows a single line diagram of a power house grounded through a neutral bus.

The selection of the proper size resistance through which the ground is to be made, is a problem for each installation. On a system already installed, it may not be desirable to change the existing relay scheme.

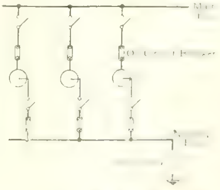


FIG. 13—GROUNDING OF NEUTRAL IN GENERATING STATION

Therefore, a resistance is put in that will limit the current in case of ground to at least twice the normal rating of the largest feeder. This usually will give sufficient current to make rapid action of the relay possible, and still not permit an excessive current which would interfere with telephone service, distort machine windings or cause too great an arc at the ground point.

Usually systems already installed have only two current transformers and two relays for overload protection. Therefore, when the neutral is grounded a third transformer and relay is added.

If the ground resistance is high, permitting a comparatively small current to flow, a relay scheme such as indicated in Fig. 14 is used. Relay *A* is an induction type overload relay with a special low current winding operating on ½ to 1½ amperes. Thus if a ground occurs on the circuit, the sum of the currents in the three current transformers is no longer zero, and the difference will flow through the relay *A*. The resistance, should, however, be of sufficient ohmic value to permit enough current to flow to operate the relay, if a ground occurs on the smallest feeder.

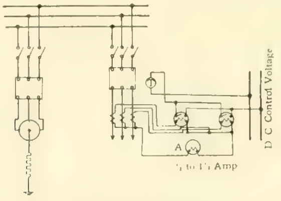


FIG. 14—RELAY ARRANGEMENT ON FEEDERS OF A GROUNDED NEUTRAL SYSTEM

The above methods of grounding the neutral provide for the tripping of the particular feeder on which the ground occurs, either instantaneously or after a short time interval, depending upon the time setting of the ground relay. This may not be desirable in all cases, due to the nature of the load on the feeders. Certain operations in the mill may require completion before the circuit be interrupted. Considerable expense and trouble may be involved if the machinery were to stop before the steel got out of the mill. With some mills the fly wheel effect no doubt would be sufficient to carry the steel through; while, with others the energy stored up in the revolving parts of the machinery may not be sufficient. In this case a longer time setting for tripping the breaker will be required than can be obtained with either the standard or the special ½ to 1½ ampere relay. Therefore, a special long time acting relay, permitting of a time setting of a few seconds to several minutes, is added to give this time duration necessary to complete the operation, as shown in Fig. 15. In addition, a relay similar to the ½ to 1½ ampere relay is supplied for the neutral ground connection to ring a bell indicating a ground. An indicating lamp is added to each feeder to show the operator on which feeder the ground has occurred. This permits operator to issue warning if necessary that the mill operation is to be hastened through. An ammeter is provided for indicating the magnitude of the ground current.

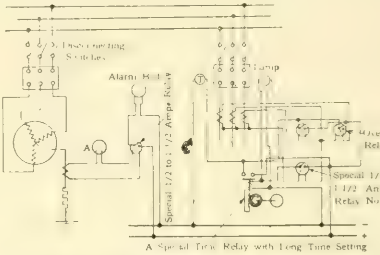

Disconnecting Switches
Alarm Bell
Lamp
A
Special 1/2 to 1 1/2 Amp. Relay
Overload Relay
Special 1/2 to 1 1/2 Amp. Relay No A
A Special Time Relay with Long Time Setting
−
+

FIG. 15—GROUNDED NEUTRAL CONNECTION
With special relay to hold the feeder in service for a definite length of time, in order to permit the completion of a mill operation.

Embedded Temperature Detectors in Large Generators*

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When the built-in detector method of temperature measurement was first proposed in 1913 and 1914, it was believed that it provided a way by which the temperature of the copper—inside the insulation—could be very closely approximated by a device installed outside the insulation. When the detector—be it thermo couple or resistance coil—is properly installed, it does measure a temperature much nearer the inside copper temperature than does any other established method, but if the detector is not properly installed, even though located between coil sides, it will give considerably lower results.

DESIGNING and operating engineers are interested in armature coil temperatures from two different standpoints; they are interested in the effects of heat on the insulation and from this standpoint are concerned that the temperature at no point in the entire winding shall exceed the safe operating temperature of the insulation; they are also interested in the linear expansion of the straight part of the armature coil due to temperature changes and, from this standpoint, they are interested in the *average* temperature of the entire length of the coil located in the armature slots.

The ideal measuring device from the standpoint of the effect of heat on insulation is a detector, such as the thermocouple, that will measure local temperatures; although, obviously such a device should be located where the highest temperatures exist. The best device to gage the effect of heat in causing the winding to "creep" and chafe the insulation is a device, such as a long resistance coil, that will average the temperature along the length of the armature coil.

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*Revised by the authors from a paper before the A. I. E. E., July 30, 1920.

A discussion of errors of measurement requires that some standard of reference be established. The only satisfactory reference temperature is the temperature of the copper inside the insulation as obtained by direct measurement. In general, the statements made in this paper are based on tests in which such actual copper temperatures have been measured by thermocouples placed in contact with the copper, the leads of the thermocouples being carried through the armature coil insulation. These inside temperatures can be measured accurately and can be checked consistently. Practically all the factors that lead to errors, when temperature detectors are located on the outer surface of the insulation, disappear when a flat ribbon thermocouple is placed in metal-to-metal contact with the copper conductor.

When a detector is placed between two coil sides in a slot, the detector measures the actual temperature inside the insulation providing:—

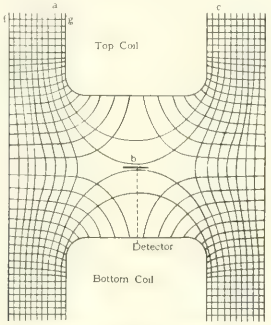


FIG. I—ISOTHERMAL LINES IN SLOT INSULATION

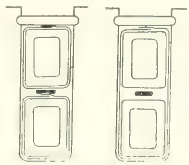
1—That there is no flow of heat from the adjacent sides of the copper in the upper and lower coils to the slot sides; and

2—That there is no difference in temperature between the upper and lower coil sides. In practically all machines both are present.

FLOW OF HEAT TO THE SLOT SIDES

The longitudinal conductivity of insulating material is considerably greater than the transverse*, approximately 1.5 to 4 times. When built up in the usual manner around a coil, the transverse conductivity is considerably decreased, so that the longitudinal conductivity may be three to ten times the transverse.

A difference in temperature between two bodies separate by a thermal conducting medium causes heat to flow through the medium in much the same manner as a difference of magnetic potential between magnets causes a flow of magnetic flux. Thus the heat flow lines and isothermal lines may be represented in the same manner as magnetic lines of force and magnetic equi-potential lines. In Fig. 1 is shown a portion of a slot and the approximate lines of heat flow as well as the isothermal lines. As drawn, the assumption was made that the insulating material was isotropic, not of greater conductivity in one direction than the other. It is evident that the path of heat flow from the portion of the copper under consideration is in part transverse to, and in part longitudinal with, the insulation. In accordance with this figure, there is heat flow from the adjacent sides of the copper in the two coils to the slot sides, which heat flow is, in the actual case, augmented by the relatively high longitudinal thermal conductivity. The particular isothermal line *abc* is at that temperature which is recorded by the detector at *b*, and the drop in temperature from the copper to the detector is approximately $\frac{(ga)}{(gf)} \times$ temperature difference between copper and iron. The actual case is too complicated to admit of accurate analysis, but an idea of the difference between the copper and detector temperatures can be gained from data on the 12 000 kv-a. alternator and small model given in this paper. The importance of this factor depends largely on the distance between copper conductors in the upper and lower coil sides. It may have little effect in low-voltage windings but may be of considerable importance in 11 000 to 13 000 volt generators in which the copper of the two coil sides is separated by at least 0.5 inch of insulation.



FIGS. 2 AND 3 ARRANGEMENT OF SLOT CELLS

DIFFERENCE IN TEMPERATURE BETWEEN THE UPPER AND LOWER COILS

In practically all alternating-current machines there is a difference in temperature between the copper in the two coils, in which case the detector cannot read higher than the average of the two. Although a number of factors may contribute to such difference, most of them are of minor influence, and only eddy currents induced by the load current will be considered.

Owing to the rate of change of leakage flux due to the load currents, the current density in the conductors is a minimum at the bottom of the lower coil, and increases with increasing depth of conductor. Thus, the loss in the upper coil is greater than in the lower coil, and consequently the temperature of the upper coil is usually higher than that of the lower. A striking example of this was shown by the tests on the original Niagara generators.* Those tests showed that with a load of 980 amperes, the maximum temperature of the top coil was 224 degrees, of the bottom coil 168 degrees (the average of which was 196 degrees), whereas the couple between coils showed 185 degrees. Thus, the difference between the top coil temperature and that given by the couple between coils was 39 degrees. While this is admittedly an extreme case due to the use of solid bars in a two-layer winding, eddy current conditions, even when all possible precautions are taken, are an important factor of design in the larger 60-cycle generators of the present day.

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*"The Thermal Conductivity of Insulating and Other Materials"—T. S. Taylor, in the JOURNAL for Dec., 1919.

*"Experimental Data Concerning the Safe Operating Temperature for Mica Armature-Coil Insulation"—F. D. Newbury, *A. I. E. E.*, Vol. XXXIV, p. 2747.

The eddy current loss in the top coil is reduced by the throw of the coils. Thus, if there are three phases with the usual six-phase grouping, and the throw of the coils is two-thirds of full pitch, the load currents in the upper and lower coils are displaced from each other by 60 electrical degrees. The density of the leakage flux interlinking the upper coil is reduced by the displacement and the eddy loss is lowered thereby. If the throw of the coils is one-third of full pitch with three-phase winding (six-phase grouping), the currents in the upper and lower coils are out of phase by 120 electrical degrees. The reduction in eddy loss in the upper coil is greater when the displacement between currents is changed from 60 to 120 degrees than when it is changed from 0 to 60 degrees.

If in a three-phase machine the throw of the coils is between full pitch and two-thirds pitch, in some of the slots the currents in the two coils are in phase with each other, and in other slots the currents are displaced by 60 degrees. Hence, there is a difference in eddy loss in the top coil in some slots from that in other slots. Similarly, with a throw between one-third and two-thirds, the eddy loss differs in some slots from that which obtains in other slots.

In a two-phase machine with a throw of coils between one-half and full pitch, some slots have coils in which the currents are in phase and other slots have coils in which the currents are displaced by 90 degrees. If the throw is less than 90 degrees, in some slots the currents are in phase opposition, which gives the minimum loss.

In a three-phase, two-pole, 60-cycle, turbogenerator that has been in service for about six years, with fairly deep conductors in the coils, there are 36 slots, and the throw of the coils is from slot *1* to slot *12*. Thus, the throw is between one-third and two-thirds of full pitch. Tests showed that with 60 electrical degrees phase displacement the temperature rise by thermocouple between coils was 63 degrees C., whereas with 120 degrees phase difference, the temperature rise was 56 degrees; a difference of seven degrees.* It is therefore evident that the temperature detectors should be located in slots in which there is minimum phase difference between the currents in the upper and lower coils.

PROTECTION OF DETECTOR FROM THE COOLING AIR

With the usual two coil per slot arrangement there are two methods of wrapping the mechanically protecting slot cell around the coils, viz.:—

1—To place these cells on coils individually as shown in Fig. 2, or,

2—To use a single slot cell to wrap both coils as indicated in Fig. 3.

With the usual radial scheme of ventilation (that is, with air ducts at intervals axially), it would seem that there is likelihood of the cool air passing between coils and cooling the detector below the temperature that would otherwise be read. This cooling air would not, however, have an appreciable effect upon the temperature of the coils, because the percentage increase in surface exposed to the cooling air is negligible.

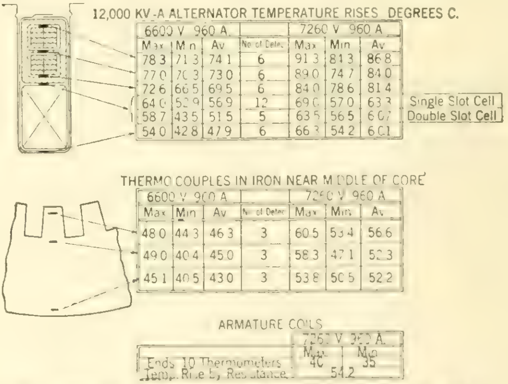
TESTS ON A 12 000 KV-A., THREE-PHASE, 60-CYCLE, 6600-VOLT, 150 R.P.M., VERTICAL ALTERNATOR

The stator of the alternator had the following dimensions:—

Internal diameter = 192 inches
External = 200 inches
Core width = 33 inches
Number and size of radial vents = 13, half-inch
Number and size of slots = 324, 0.79 by 3.45 in.
Number of conductors per slot = 4
Size of conductor = 4(0.162 by 0.25 in. bare) 4(0.129 by 0.21 in. asbestos covered)
Section of conductor = 0.264 sq. in.
Arrangment of conductor shown in Fig. 4.
Connection, two-circuit star.
Throw of coils 1 and 7.

In order to make tests with thermocouples on the bare copper, these couples were installed in coils near the neutral point, and the neutral was grounded during the tests. In addition to these couples, the two-cell, and the one-cell arrangements were used—two cells from the center line of the machine to the right, and one cell to the left. The thermocouples were placed in the iron adjacent to the central vent. Thermocouples were also embedded in the iron axially, at the middle of the package to the right of the central vent, as shown in Fig. 4.

Two heat runs were made: first at 6600 volts, 960 amperes per phase until a constant temperature was



12,000 KV-A ALTERNATOR TEMPERATURE RISES DEGREES C.

6600 V 960 A.				7260 V 960 A			
Max	Min	Av	No. of Detec.	Max	Min	Av	
78.3	71.3	74.1	6	91.3	81.3	86.8	
77.0	70.3	73.0	6	89.0	74.7	84.0	
72.6	66.5	69.5	6	84.0	78.6	81.4	
64.0	52.9	56.9	12	69.0	57.0	63.3	Single Slot Cell
58.7	43.5	51.5	5	63.5	56.5	60.7	Double Slot Cell
54.0	42.8	47.9	6	66.3	54.2	60.1	

THERMO COUPLES IN IRON NEAR MIDDLE OF CORE

6600 V 960 A				7260 V 960 A		
Max	Min	Av	No. of Detec.	Max	Min	Av
48.0	44.3	46.3	3	60.5	53.4	56.6
49.0	40.4	45.0	3	58.3	47.1	52.3
45.1	40.5	43.0	3	53.8	50.5	52.2

ARMATURE COILS

	7260 V 960 A.	
	Max	Min
Ends 10 Thermometers	40	35
Temp. Rise by Resistance	54.2	

FIG. 4—TEMPERATURES OBTAINED IN A 12 000 KV-A, 6600 VOLT ALTERNATOR

reached; then, without shutting down, the voltage was raised to 7260, the current being kept at 960 amperes. Both runs were made at nearly zero power-factor, lagging. The summary of these heat runs is given in Fig. 4. The ingoing air temperature was 31 degrees, so that for the first heat run the total temperature of the top coil was about 107 degrees C. The calculated eddy current loss for the top coil is 48 percent of the I^2R loss*. The I^2R loss at zero degrees C. with 960 amperes, per inch of length per coil is 1.09 watts. The average surface (taken as bare copper surface plus three times the distance from copper to iron) is 3.31 sq. in., the thickness of the single wall = distance copper to iron is 0.154 inch; the thermal conductivity of the insulation we shall take as 0.003 watts per inch cube per degree C. Then the watts per square inch at 107 degrees C. =

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*The temperatures were measured by means of thermocouples between coil sides, not on the bare copper.

$$\frac{(1 + 0.00427 \times 107)\ 1.48 \times 1.09}{3.31} = 0.707$$

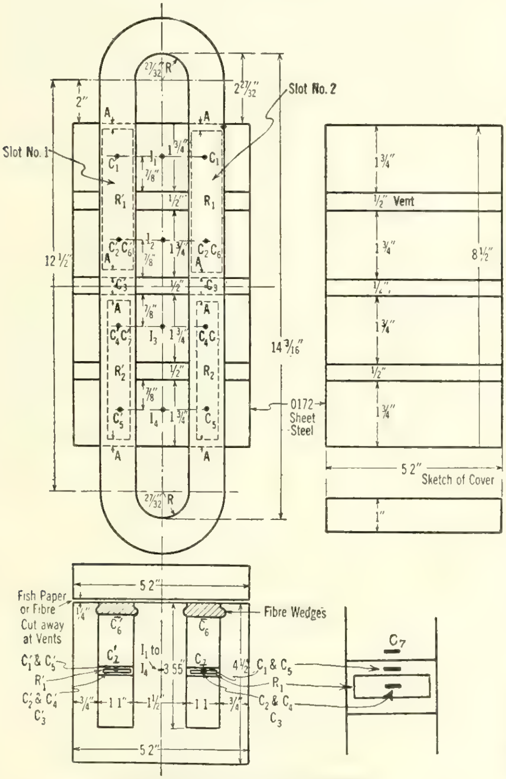

FIG. 5 MODEL OF ARMATURE SLOTS

The thermal drop from the copper to the iron is approximately: $\frac{0.707 \times 0.154}{0.003} = 36.2$ *degrees C.*

The temperature rise of the iron, 48.5 degrees C. in the first run, is taken as the mean of the maximum thermocouple readings in the teeth and just back of the teeth. Taking the air in the vents at the teeth to be 10 degrees above the ingoing air (for second run 13 degrees) the weighted mean temperature of iron and air is:

$$\frac{48.5\ deg \times 26\tfrac{1}{2}\ in + 10\ deg \times 6\tfrac{1}{2}\ in}{33\ in} = 40.8\ degrees\ rise$$

The temperature of the copper above the ingoing air is then: 36.2 + 40.8 = 77 degrees; whereas the average temperature rise by test of the top coil in the slot which showed maximum temperature was 76 degrees. The calculations do not allow for axial flow of heat in the copper to the ends, but the decrease in temperature at the middle due to longitudinal flow in this machine is not great.

The calculations are summarized in Table I.

TABLE I

	6600 Volts 960 Amperes	7260 Volts 960 Amperes
Weighted mean of tooth and air temp..	40.8	50.4
Thermal drop through insulation......	36.2	37.1
Calculated copper temp. rise = sum of above	77.	87.5
Average temp. rise of the coil in slot having max temp. (test)...........	76.	88.1

This close agreement between the calculated and observed drop in temperature through the insulation under two different load conditions indicates the overall consistency and reasonableness of the test results, and permits us to draw conclusions from them with added confidence. Attention is especially called to fact that the drop through the insulation cannot be altered by a change in ventilation, except for a slight change in loss due to the resistance being modified by a change in total temperature. The only way the heat can be dissipated from the copper is by conduction through the insulation; some of the heat may flow longitudinally but still must be conducted through the insulation on the coil ends and then be liberated by convection from the surface.

TABLE II

		6600 Volts 960 Amperes Degrees	7260 Volts 960 Amperes Degrees
Average temp. rise of top coil in slot having max. temp....................		76.	88.1
Couples between coils	Max. temp. rise single slot cell	64.0	69.0
	Max. temp. rise double slot cell	58.7	63.5
Average temp. rise bot. of slot.........		47.9	60.1
Average temp. rise teeth.............		46.3	56.6

The readings may be summarized still further as in Table II, from which it will be seen that:—

1 There is a very material difference between the true copper temperature and the temperature as measured by means of detectors between coil sides; 12 degrees and 10 degrees for the 6600 and 7260 volt heat runs respectively. These differences are due to a combination of effects, such as heat flow to the sides, and difference in temperature between upper and lower coils. Expressed as a percentage of the total drop in temperature from the copper to the weighted mean of iron and air (76—40.8 degrees for the first run), these differences are 34 per cent for the first and 51 per cent for the second heat run.

2—The temperature reading is lower with the two-cell arrangement than with one cell. This amounts to 5.3 degrees for the first and 5.5 degrees for the second heat run. The differences between the maximum temperature on the copper and the maximum temperature by detector with two cells, are 49 and 65 per cent of the total drop for the first and second runs respectively. The various figures are put in more convenient form in Table III.

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*See paper by R. E. Gilman on "Eddy Currents," presented at A. I. E. E. 36th Annual Convention, 1920.

TABLE III

	6600-Volt Run		7260 Volt Run	
	Degrees	Percent Total Drop in Insulation	Degrees	Percent Total Drop in Insulation
Difference between max. copper temp and max detector reading with one cell.	12.	34	19.1	51
Difference between max. copper temp. and max. detector reading with two cells....	17.3	49	24.6	65

3—There is a considerably greater difference between the maximum and minimum readings with the detectors exposed to cooling air, as in the two-cell arrangement, than with the detectors in contact with the copper or between coils but protected from air currents. This is shown by the following figures from Fig. 4.

	Max.	Min.	Ratio
Couples on copper..........	78.3	71.3	0.91
Couples bet. coils one-slot cell............	64.	52.9	0.83
Couples bet. coils two-slot cell............	58.7	43.5	0.74

This is a matter of considerable importance, as it is a measure of the reliability of the readings by the several methods. The greater variation in the case of the two-slot cell arrangement is possibly due to the greater effect of poor contact between the coil surfaces and the detector when the detector is exposed to air currents.

4—The average temperature rise by couple at the bottom of the slot is not much higher than the average temperature rise of the teeth. The thermocouple at the bottom of the slot measures the iron temperature at that spot and cannot read the copper temperature. The difference between the two readings is quite small, but that can be readily understood when one considers that there is considerable flow of heat from the coil, which must be accompanied by a thermal drop in the iron; the longitudinal thermal conductivity of the iron is only about one-ninth that of copper.

Further conclusions may be drawn by reference to Fig. 4.

5—The temperatures by thermometers on the end windings give practically no information in regard to the maximum copper temperatures.

6—The temperature rise by resistance is, at best, the average resistance of the complete winding and therefore conveys no information in regard to maximum temperature, and little information as regards the average temperature in the slots.

TESTS WITH ARMATURE MODEL

In Fig. 5 are shown the details of a model designed to reproduce the temperature conditions in a radially ventilated armature core from which data of interest can be obtained more conveniently than in the actual generator. This model consists of sheet-steel laminations having two armature slots and built up into a core of four packages with one-half inch air ducts between. Two flat coils (connected in series) wound with small wire are located in the two slots. A second sheet steel core one inch thick, is placed over the slots to complete the magnetic circuit. The coils were insulated with mica of a thickness sufficient for a 6600 volt generator.

In Fig. 6 are shown elevations of the model when placed in a wooden box with a small Sirocco fan used for driving air through the vent-ducts.

In Fig. 5, C_1, C_2, etc., I_1, I_2, etc., all refer to thermocouples, the C couples being placed between coils, thus measuring coil temperatures, and the I couples being imbedded in the iron. R_1, R_2, R_1', R_2', are resistance exploring coils. Couple C_2 is placed within R_1; C_2' is within R_1'; C_4 is within R_2; and C_4' is within R_2'. C_1, C_5, and C_5' are above the resistance exploring coils. As shown R_1 and R_1' are substantially the entire width of the slot; R_2 and R_2' are each about 9-16 in. wide. In slot No. 1, the slot cell was made in two parts as in Fig. 2. In slot No. 2 only one slot cell was used for parts of two coils in a slot as in Fig. 3. Thus, in slot No. 1, the air in the vent-ducts could strike the detectors and effect their indication, as is proved by the results. To show that there was no appreciable difference between the two slots, data was also taken with all space between coils closed with a packing of litharge and glycerine. In Table IV the data from the heat runs with 20 amperes 60 cycles are given.

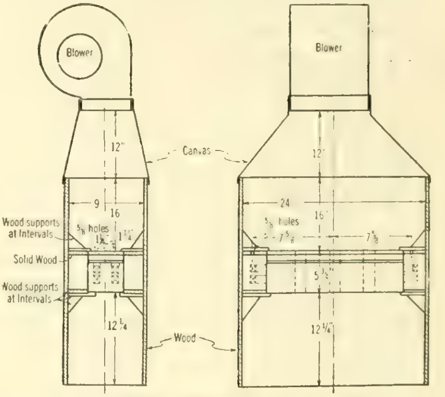

FIG. 6—SCHEME OF VENTILATION OF MODEL

TABLE IV TEMPERATURE RISES, DEGREES.
Test with Alternating Current, 20 Amperes, 60 Cycles
Approximately 374 Volts

Amperes per sq. inch = 1870.
Approx. tooth density = 92,000 lines per sq. inch
Approx. core density = 73,000 lines per sq. inch
Approx. gap density = 51,200 lines per sq. inch
Eddy current loss top coil = 0.39 x I^2R.

Without Packing Between Coils				With Packing Between Coils			
Two Slot Cells Slot No. 1		One Slot Cells Slot No. 2		Two Slot Cells Slot No. 1		One Slot Cells Slot No. 2	
C1'	— 30.6	C1	= 44.6	C1'	— 47.5	C1	= 43.5
C2'	— 34.5	C2	— 45.2	C2'	= 43.	C2	= 39.5
C3'	— 38.6	C3	— 48.2	C3'	= 43.	C3	= 41.0
C4'	= 34.6	C4	= 50.4	C4'	= 46.5	C4	= 44.0
C5'	= 32.	C5	— 48.5	C5'	= 45.5	C5	— 45.0
C6'	— 55.2	C6	— 54.5	C6'	= 54.5	C6	— 54.
C7'	= 58.	C7	— 59.6	C7'	= 58.5	C7	= 58.5
R1'	= 32.5	R1	= 45	R1'	= 43.7	R1	— 41.
R2'	= 33	R2	= 48.8	R2'	— 44.9	R2	— 42.
Entire winding by resis	= 44 deg				53 deg		
I_1	38.9	I_1	40.5	I_1	41.	I_1	39.
I_2	31.5	I_2	38.8	I_2	33.5	I_2	35.5

The temperature in the slot with two cells was materially lower than in the slot with one cell, whether measured by thermocouples or resistance coil. Table V was made up in the same manner as Tables I and II; thermal conductivity was taken as 0.003 watts per inch cube per degrees C. The air temperature rise was taken as three degrees above the ingoing air for figuring the weighted mean of tooth and air temperatures.

TABLE V

Weighted mean of tooth and air temp. . . . . = 26
Thermal drop through insulation . . . . = 29.5
Calculated copper temp. rise = sum of above = ... = 55.5
Average temperature rise of copper top coil, test. . . . . = 56.6
Couples between coils Max. temp. rise single slot cell. . . . . = 50.4
Max. temp. rise double slot cell. . . . . = 38.6

Using the same method of calculation as for the 12 000 kv-a. alternator, and using 58.8 degrees for the internal temperatures (the average of the C_7 couples), Table VI is obtained:

TABLE VI

	Degrees	Per Cent of Total Drop in Insulation
Difference between copper temp. and max. detector reading with one cell.	8.4	25.6
Difference between copper temp. and max detector reading with two cells.	20.2	61.5

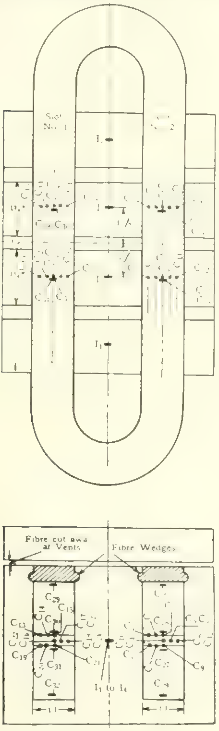

FIG 7—MODEL WITH ADDITIONAL INSULATION

From the tests on the Model it will be noted that: –

1—The air which passes between coils with the two-cell arrangement very materially lowers the reading of the detectors, whether thermocouples or resistance coils are used.

2—The air which passes between coils with the two-cell arrangement has no influence upon the internal temperatures (compare tests without packing with those with packing; also compare C_6 and C_7 readings in two different slots in the test without the glycerine and litharge packing).

3—With any detector arrangement between coils, the temperatures indicated are lower than the maximum.

4—The wide resistance coils R_1 and R_1' showed slightly lower temperatures than did the narrow coils, due undoubtedly to heat flow to the sides. (Although the same argument applies to the thermocouples, they can more readily be made narrow, and the usual practise is to make them narrower than is mechanically feasible with resistance coils).

5—The thermocouples showed slightly higher temperatures than the resistance coils, but the difference was too small to warrant much discussion other than as noted under 4 above.

The fact that the temperature rise by resistance agreed fairly well with the average of the thermocouples, inside the top coil, may be accounted for as follows:—

1—The ventilation of the ends was very poor (air was allowed to pass through ⅝-inch hole) and therefore the temperature at the ends was probably higher than in the slots, thus raising the average temperature; and

2—Very little time was lost between shut-down and taking of reading of resistance. Neither of these conditions can be obtained in a large alternator—the ends are very effectively cooled, and there is a considerable lapse of time after shutting down before readings can be taken. The latter statement implies that in a machine, the average temperature is higher than can be measured by resistance.

FURTHER TESTS ON AN ARMATURE MODEL

In order that additional proof might be secured, by a detector placed between coil sides, of the influence upon the reading (a) of heat flow to the slot sides, (b) of width of detector, (c) of difference in losses in the upper and lower coils due to eddy currents, an armature model similar to the one shown in Fig. 5, was built, Fig. 7. This model differed only from the previous one in that additional insulation was placed between coil sides, consisting of 14 layers, each 0.015 inch thick of treated cement paper and mica, and in the arrangement of the thermocouples. Those indicated as C_1 to C_{24} inclusive were made of No. 27 B. & S. gage copper and advance wire; those inside the coils C_{25} to C_{32} inclusive were made of 0.005 by 0.25 in. copper and advance ribbons.

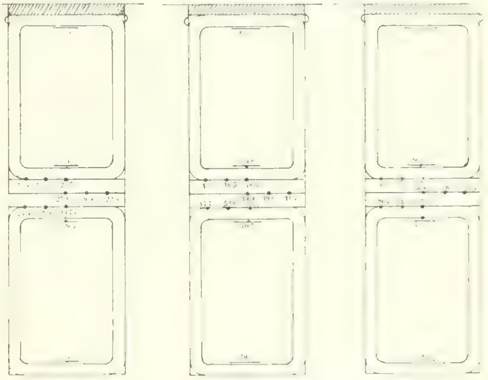

FIG. 8—TEMPERATURE RISES IN MODEL

Tests were made on this model with direct current, so that there was no eddy current loss; in order to imitate the greater loss in the upper coil which usually obtains when alternating-current flows, different values of direct current were used in the two coils. In Fig. 7 there are thermocouples in corresponding positions in slots *1* and *2*, and in Fig. 8 the averages of the temperature rises are recorded for symmetrical points, above the ingoing air in degrees C. In Fig. 8 the temperatures are averaged from two thermocouple readings, except those at the middle of the extra insulation between coils, the recorded temperature rises then being the average of four readings.

A study of the 20 ampere and 25 ampere heat runs shows that they are consistent, if due allowance is made for the increase of the resistance of copper with temperature, and for the weighted mean of iron and air temperatures. The third heat run, with different values of currents in the two coils, is also as consistent with the first two runs as may be expected with temperature tests, due allowance having been made for iron temperatures.

It will be noted that:—

1—There is a large difference in temperature between the inside and outside of the coil insulation.

2—There is a comparatively small difference in temperature between the outside of the coil insulation at the center of the slot and the middle of the extra insulation.

3—There is a marked temperature gradient from the center of the slot to the slot sides.

4—With different values of current in the two coils, there is a greater departure of temperature at the midpoint between coils from the copper temperature in the upper coil than with equal currents in the two coils.

5—Although the internal temperatures of the two coils are substantially the same at symmetrical spots with equal currents, there is a considerable difference between the temperatures on the outside of adjacent coil sides.

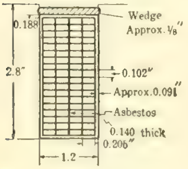

FIG. 9—ARRANGEMENT OF CONDUCTORS IN A SLOT

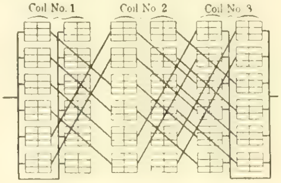

FIG. 10—TRANSPOSITION OF STRANDS

6—The internal temperatures for symmetrical spots in the two runs with equal currents on the two coils differed very little from each other.

7—The internal temperatures at the top of the upper coil and at the bottom of the lower coil were lower in all three runs than the internal temperatures in the sides of the coils adjacent to each other.

The data prove the statements given previously that there is appreciable heat flow to the slot sides; that the detector between coils does not read the true copper temperature; and that the width of the detector influences the reading.

Conclusion 5 brings out the fact that there may be discrepancies of considerable magnitude as a result of unequal thermal conductivities in the insulating wall. Although there may have been minor factors which affected the temperatures at the outside of the coils, the difference in thermal conductivities, due perhaps to better surface contacts between layers of insulation on one coil side than the other, permitted greater rate of heat flow from the upper coil than from the lower. That the internal temperatures were only slightly influenced thereby, is probably because the rate of heat flow from the other sides were nearly equal in the two coils. The temperature rises of symmetrical points in the two slots also were different. Thus, in the 25 ampere run, the temperature rises at positions C_8 and C_{15} (Fig. 7) were 44 and 53 degrees respectively, an average of 48.5; and for C_9 and C_{21}, 57 and 54.5 degrees, an average of 55.7 degrees.

If conclusion *6* were applicable generally, the temperatures on the copper could be taken in a smaller number of places in a machine than with the usual method with detectors between coil sides. Data in Fig. 4 and in conclusion *3* following Table III also show that the percentage difference is smaller for internal differences than between coil sides.

Conclusion *7* should be considered in conjunction with the following paragraphs which relate to the "Location of the highest copper temperature". Owing to the relatively high thermal conductivity of the fibre wedge (the wedge was thinner than those ordinarily used) the rate of heat dissipation from the top of the upper coil was sufficiently great to reduce the temperature below that of the copper at the bottom of the same coil.

ERRORS IN DETERMINATION OF TEMPERATURES BY PLACING DETECTORS BETWEEN COIL AND IRON OR UNDER WEDGE

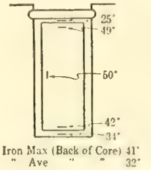

FIG. 11—LOCATION OF THERMOCOUPLES

Previous reference to errors by this method has been made. A test on another machine will show the futility of attempting to measure copper temperature with detectors, say, between bottom of coil and slot, and between coil and wedge.

A 3750 kv-a., three-phase, 60-cycle, 480-volt, 3600 r.p.m. turbo-generator was wound with one coil side per slot, one turn per coil, the connections being two-circuit star. The arrangement of the conductors in the slot is shown in Fig. 9, there having been 72 strands per conductor, each 0.102 by 0.205 in. d. c. c. The coils were turned over at the ends; that is, a strand at the top of a coil in one slot became the bottom strand in the slot in which the other part of the coil was placed. In addition the strands were transposed depthwise, as indicated schematically in Fig. 10. There were 36 slots total, so that the number of coil-sides per pole per phase per circuit was three. The three coils in such a phase group formed a group for transposition. Thus, starting at the beginning of a phase group, all the strands were joined together at one end of the coil, but at the other end the 72 strands were arranged in 12 groups, of six strands each. The top left group at the beginning of coil No. 1 becomes the bottom left group at the end of coil No. 1. To simplify the sketch in Fig. 8, the left sides of the 12 groups of coil No. 1 are shown joined in parallel; these are the beginnings of the coil group. At the other end of coil No. 1, the position of the groups is actually inverted. Then, the top left group which is actually the bottom left in coil No. 1 is joined to the third left group in coil No. 2; and the other end of that group is joined to the fifth left group in coil No. 3, etc.

Thermocouples were placed at the middle of the straight parts of a coil, before the coils were insulated, and couples were also placed at the bottom and top of the slot, as shown in Fig. 11. In the same figure the final temperature rises are indicated for a heat run at 4100 amperes per phase, normal voltage, zero power-factor.

Calculating the drop through the insulation in the manner previously explained, allowing 0.091 in. for the thickness of the insulation; 0.3 for the watts per sq. in. at 0 degrees; 0.2 for the eddy loss as fraction of I^2R; 1.32 for the increase in resistance due to temperature; 0.0025 for the thermal conductivity;* the drop is:

$$\frac{1.2 \times 1.32 \times 0.091 \times 0.3}{0.0025} = 17.3 \textit{ degrees.}$$

The weighted mean of iron (34 degrees) and air (say 10 degrees) for relative lengths of 3.33 to 1 is 28.4 degrees. The mean of the three temperatures inside the coil is 47 degrees, and the drop is 47 — 28.4 = 18.6 degrees as compared with 17.3 degrees calculated.

It will be noted that:—

1—The detector at the bottom of the slot or under the wedge does not indicate the temperature of the copper.

2—The maximum temperature of the copper is probably not at either the top or at the bottom of the coil.

3—The cool currents of air above the wedge may cause the detector below it to read lower than one at the bottom of the slot, even though the copper at the top is at higher temperature.

As a matter of fact, as was pointed out in commenting upon the tests on the 12 000 kv-a. alternator, the detector at the bottom of the slot reads the temperature of the iron with which it is in contact; the detector placed below the wedge reads the temperature of that portion of the wedge, and neither can take into account the drop through the insulation. The A. I. E. E. Standardization Rule No. 356 allows for a correction factor of ten degrees C. plus one degree C. per 1000 volts above 5000. Such a correction factor has little meaning. Thus, the tests and calculations on the 12 000 kv-a. alternator showed that the drop through the insulation was approximately 36 degrees with 91 percent load or about 43 degrees with full load. With high voltages, especially in long-core 60-cycle machines of large output, the drop is necessarily greater, due to the heavier wall of insulation; in such machines the drop is of the order of 50 degrees C.

In our opinion it is not possible to decide upon correction factors which are applicable, even for comparison, with the one coil per slot arrangement. In point of fact, machines built at the present time in large or moderate sizes (in which detectors are incorporated), have with very few exceptions, two coil-sides per slot. Therefore, the method of measuring copper temperatures by means of detectors at the bottom of the slot or under the wedge, should not be recognized.

LOCATION OF THE HIGHEST COPPER TEMPERATURE

It will be seen from Fig. 4 that the temperatures at the top of the upper coil are slightly higher than at the middle of the upper coil, but that there is a larger difference in temperature between the middle and the bottom of the coil than between the top and the middle of the coil. In the model (see Table IV) the temperatures at the bottom of the upper coil are higher than at the top. In the 3750 kv-a. generator (Fig. 11) the temperature at the side was substantially the same as at the top, but the temperature of the copper at the bottom of the coil was appreciably lower than at the side. In all three cases, the effect of eddy currents was to increase the loss toward the top of the coil; but the fact that the temperature at the top was lower than might have been anticipated was in every case because the thermal conductivity of the compact wedge was relatively high, and with the effective cooling of the outside of the wedge, the temperature at the inside was lowered.

If the temperature of the bare copper is to be measured, detectors should be located at various depths within the upper coil, and the maximum temperature taken to be the maximum copper temperature. If this is done in a number of coils in the machine and if the detectors are so located axially that their positions correspond to the axial position of maximum core temperature (to be determined by test on similar machines before manufacturing the coils) the maximum copper temperature will be measured with a very small percentage error.

CONCLUSIONS

The points brought out in this paper may be summarized as follows:—

1—With detectors placed between coil sides, the difference in eddy currents in the upper and lower coils causes the detectors to read lower than the maximum.

2—With detectors placed between coil sides, the flow of heat to the slot sides causes the detectors to read lower than the maximum.

3—With detectors placed between coil sides, the phase difference in currents in the particular slot influences the reading, and the detectors should be located in slots in which there is minimum phase difference.

4—With detectors placed between coil sides the possible circulation of air about the detector may have a material influence upon the reading of the detector. The slot cell should be so arranged that air currents cannot influence the reading of the detector. (See Fig. 3.) The single slot-cell provides excellent protection as the detector is then located in dead-air space.

5—The air currents which lower the reading of the detector with the two-cell arrangement have an inappreciable influence upon the internal copper temperature.

6—All heat from the copper must flow transversely through the insulation.

7—The thermal drop through the insulation in large, long-core, high-voltage, 60-cycle machines is of the order of 50 degrees C.

8—The thermal drop through the insulation cannot be appreciably lowered—at least in long-core machines—by improvement in ventilation.

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*The lower value of conductivity was chosen at the lower voltage because of the greater relative influence of air pockets with the thinner insulation.

9—With any arrangement of detectors between coil sides, temperatures lower than the maximum are read, with the possible and rare exception of copper temperatures equal to or lower than the iron temperatures.

10—There is a marked temperature gradient from the center of the slot to the slot sides. Therefore, with wide detectors between coil sides, lower readings are obtained than with narrow detectors. The detectors should be made as narrow as is mechanically feasible.

11—With detectors placed on the bare copper, the maximum temperature is not necessarily read at the top of the upper coil.

12—A detector placed between coil side and iron or between coil side and wedge reads only the iron or wedge temperature at the particular spot; the reading gives no information in regard to the thermal drop through the insulation and the actual copper temperature.

13—Thermometers placed on the end windings give no information in regard to the highest copper temperature in large high-voltage generators.

14—Resistance measurements taken after completion of the heat run, convey no information in regard to maximum temperature, and but little information in regard to the average temperature in the slots.

15—The machine usually cools too much after shutdown and before taking readings to obtain accurate data on the average temperature of the winding.

16—There seems to be a greater degree of consistency between readings taken at symmetrical spots on the bare copper than by any recognized method of placing detectors. There seems to be more consistency with the one-cell than with the two-cell arrangement.

Eddy Current Losses and Temperatures of Stator Coils

In Alternating-Current Generators

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This article is intended to show some of the applications of the formulae derived by Mr. R. E. Gilman in his paper on the "Theory of Eddy Current Losses in Armature Conductors," presented at the June meeting of the American Institute of Electrical Engineers and furthermore by the aid of this formulae to calculate the losses in several coil arrangements and the temperature drop through the coil insulation.

PREVIOUS articles on the eddy current theory in armature conductors have developed loss ratios for two limiting conditions, one for a solid bar and the other for a conductor composed of an infinite number of strands in parallel. Between these limits lie the majority of coils in use in which the conductor is composed of a finite number of strands in parallel. Previous to Mr. Gilman's study of the problem of eddy currents in armature conductors, only an estimate could be made of what the increased loss might be. For instance, the assumption was sometimes made in calculating the temperatures in short machines, that the eddy current loss was equal to the loss transmitted longitudinally through the copper, or the eddy current factor was calculated for a

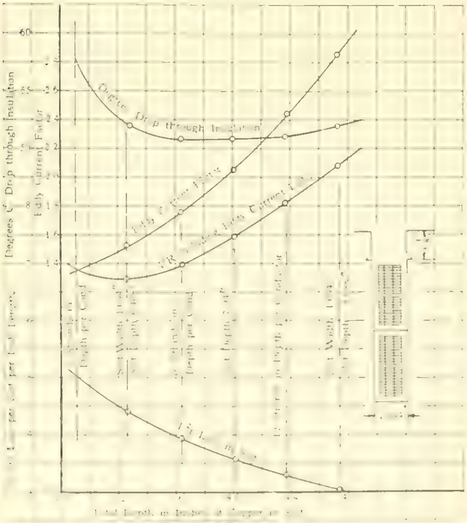


FIG. 1—COPPER LOSS AND TEMPERATURE CURVES

Based on a 31 250 kv-a, 13 2000 volt, three-phase, 60 cycle generator with two parallel circuits.

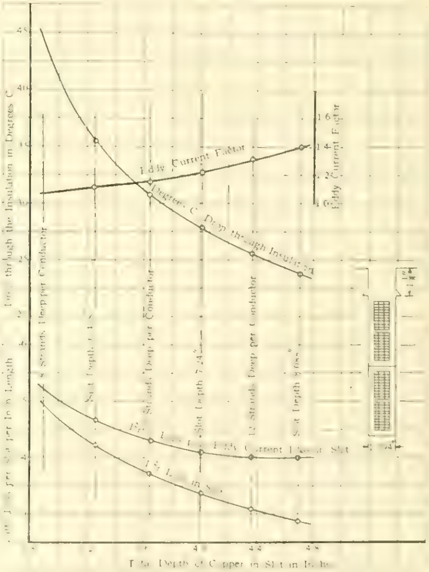


FIG. 2—COPPER LOSS AND TEMPERATURE CURVES

Based on a 31 250 kv-a; 13 200 volt, three-phase, 25 cycle generator with four conductors per slot and continuous stranding.

solid bar and then for a conductor with infinite stranding, and a factor chosen somewhere between the two. The effects on the eddy current factor of different coil combinations were unknown. It was not known, for instance, what the result would be if the coil were made in two pieces and the strands short-circuited at both ends of the coil, instead of making stranding continuous. Until the present, therefore, any estimate on the eddy current loss in an armature coil could hardly have been more than a guess. Many of the older coils have been found to have an eddy current loss double that of the copper loss, and even in a modern coil, and with the aid of this knowledge, the eddy current loss will seldom be less than twenty or thirty percent of the copper loss.

As an example, in the application of these formulae we will consider several coil designs for a 31 250 kv-a., 13 200 volt, three-phase machine on both sixty and twenty-five cycles, and from this study several interesting results can be shown.

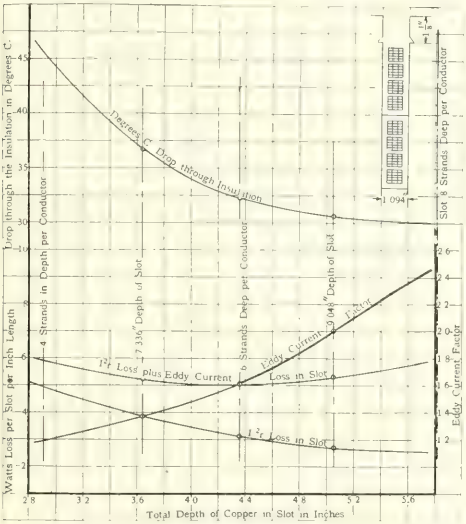


FIG. 3—COPPER LOSS AND TEMPERATURE CURVES

Based on a 31 250 kv-a, 13 200 volt, three-phase, 60 cycle generator, having eight conductors per slot and continuous stranding.

A number of curves have been worked up showing the relation between loss and temperature drop with varying depth of copper. These curves have been calculated on the basis of a rise on the iron surrounding the coil of 55 degrees C., and a temperature of inlet air of 40 degrees C., giving a total temperature of iron of 95 degrees C. The length of the machine being great enough, it was assumed that there is no heat transfer from the point under discussion to the end windings and all the heat is conducted through the insulation. The assumption has also been made that the amount of heat transmitted per square inch is uniform around the slot. For purposes of calculating the temperature drop, the surface through which the heat flows has been taken as the mean between the bare copper and the periphery of the slot. The temperature of the iron and the thermal conductivity of the insulation have been assumed constant at all points. Since the temperature drop is unknown, and this must be known in order to calculate the eddy current factor and the temperature coefficient of the copper, it was first necessary at each point to calculate a preliminary curve of three points by assuming three temperature drops and working backward to find the loss and current for each temperature. A curve was then plotted between current and temperature drop and from this curve the temperature drop was taken for the rated current.

The assumption of constant temperature of the iron, has little effect on the loss in the coil, and the consequent drop through the insulation, because with decrease in temperature, for instance, the temperature coefficient of the copper decreases, but the eddy current factor increases and results in the product of the two being very nearly constant.

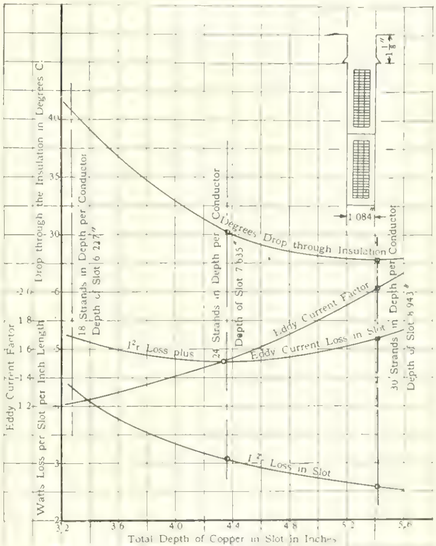


FIG. 4—COPPER LOSS AND TEMPERATURE CURVES

Based on a 31 250 kv-a, 13 200 volt, three-phase, 60 cycle generator, having two conductors per slot with each conductor transposed.

In Fig. 1 are shown curves of a two-turn per coil winding stranded continuously, two coils per slot. The eddy current factor is calculated as per case *D*. Each conductor consists of strands 0.182 in. wide by 0.091 in. thick and is three strands wide. Starting in with eight strands in depth, and increasing in steps by one strand on each conductor up to thirteen strands in depth per conductor, the losses and temperature drop at each point have been plotted against total copper depth in the slot. From these curves it is evident that beyond a certain point the temperatures are not decreased by increasing the copper depth, and that a point may be reached where an increase in copper really increases the copper temperature, because of the rapid increase in the eddy current loss. In contrast, if this same coil were used on twenty-five cycles, mechanical limitations in the coil are reached with increasing coil depths before reaching a point of constant temeprature. The curves for this coil on twenty-five cycles are shown in Fig. 2. The depth of the slot given on the curves includes the dimension of 1⅛ inch covering the wedge and open section of slot above the wedge. On all these curves there is also shown a curve giving eddy current factor for each point. This factor, if multiplied into the copper loss, gives the sum of the copper loss and eddy loss.

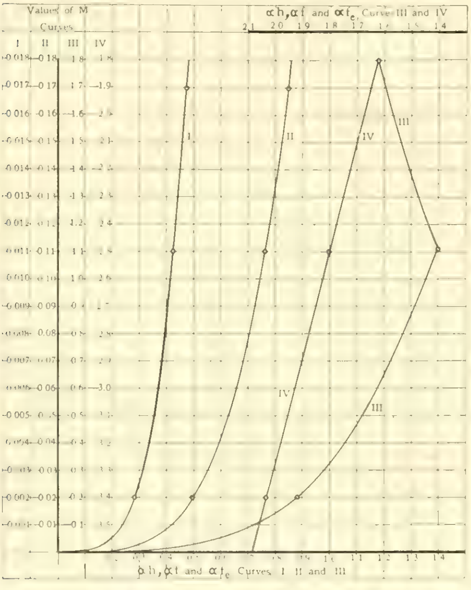


FIG. 5—VALUES OF M_s AND M_e FOR VARIOUS VALUES OF αh AND αf.

$$M = 4\alpha h\frac{(\sinh\alpha h - \sin\alpha h)(\cosh\alpha h - \cos\alpha h)}{\cosh 2\alpha h + \cos 2\alpha h}$$

Curves I, II, III and IV are continuations of the same curve to a different scale.

If we had used a four-turn coil, which would be possible by connecting the coils per phase in twice as many parallels, a considerable gain in temperature drop is obtained, as shown in Fig. 3, giving approximately 19 degrees improvement at a point of 4.36 inches total copper depth of slot.

One other possibility in the design of the coil lies in the use of a transposed coil, instead of a multi-turn coil. In this type of coil, the strands must be a multiple of the slots per pole per phase, in this case six. Fig. 4 is, therefore, calculated at 18, 24, and 30 strands in depth per coil. The eddy current factor is calculated as per case *E*, where *m* (conductors per slot) equals *12* and the strands per conductor are *3*, *4* and *5*. This coil is slightly better than the four-turn coil, and also reaches a point beyond which there is no gain in temperature. The point of 24 strands in depth per conductor in the transposed coil can be compared with the four-turn coil and six strands per conductor, or the two-turn coil with twelve strands in depth per conductor, as all three coils have the same copper depth. The four-turn coil and the transposed coil have practically the same temperature drop, differing only because of a slight difference in thickness of insulation, due to the absence of conductor insulation in the transposed coil. Either of these arrangements is considerably better than the two-turn coil. All these curves show an increase of total loss in the coil before a corresponding increase occurs in the drop through the insulation, which means that for a period the surface of the coil increases at a faster rate than the loss.

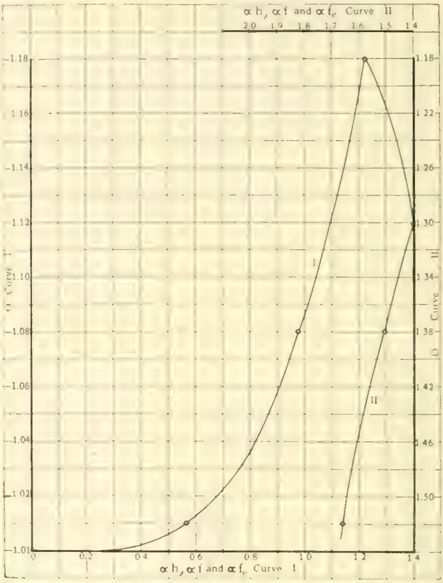


FIG. 6—VALUES OF Q_s AND Q_e FOR VARIOUS VALUES OF αh AND αf.

$$Q = \left[\frac{\sinh 2\alpha h + \sin 2\alpha h}{\cosh 2\alpha h - \cos 2\alpha h}\right]\alpha h$$

$$Q = 1 + \frac{8}{[illegible]}(\alpha h)^4 \text{ for small values of } \alpha h$$

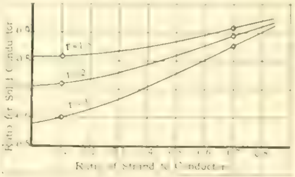


FIG. 7—MULTIPLICATION FACTOR FOR αf.

Ratio for solid conductor [illegible]

All these curves have been carried farther than it is mechanically possible to build coils for large machines. Being continuous coils, not made in halves and connected together in front and back, they would become too heavy to be handled without danger of injuring the insulation. Also, the great depth of the coil results in a considerable difference in length of chord in the bottom and top of the slot and makes it almost impossible to enter the coil at the top of the slot without seriously twisting it, and damaging the insulation.

It would be possible to use coils of this great depth if they were formed in halves and then connected together in front and back. It is impracticable, however, to connect each strand individually, owing to the large number of strands, and if all the strands are connected solidly together on both the front and rear ends, the eddy current loss is increased tremendously. For instance, if the four-turn coil of seven strands in depth per conductor were connected front and back, the eddy current factor as calculated by class *B* would be increased from 2.12 for a continuous coil to 5.7, and the drop through the insulation increased from 31 to 93 degrees C. This is for a depth of slot of 9.048 inches, which is deeper than has been used and, were it used, would probably necessitate a two-piece coil.

From a consideration of the curves, it is theoretically possible on sixty cycles, and with 13 200 volt insulation, to obtain a drop through the insulation of approximately 30 degrees C. as a minimum. Practically, however, this result cannot be obtained because of mechanical limitations. So far, a slot deeper than 6 to 6.75 inches has not been used, and for such a slot, by using a transposed coil or a multiconductor coil, the temperature drop from bare copper to iron will be approximately 40 degrees C.

These facts have considerable practical importance in view of the demand in some quarters for low temperatures, and the feeling that the designer advocates higher temperatures merely to reduce sizes and costs. These figures show that the designer faces definite physical limitations in large high voltage 60-cycle turbogenerators, and true copper temperature rises approaching 100 degrees C. cannot be avoided.

Listed below will be found the formulae derived by Mr. Gilman which are expressed as a ratio R which, multiplied into the copper loss, gives the sum of the copper and eddy current loss. Where there are two coils per slot a ratio is given for the top R_t and bottom R_b coils and gives the average loss in each coil. A short explanation of each formula follows the list.

A—When the conductors are solid bars (2 coils per slot),

$$R_t = \left[\frac{m^2-1}{3} + \frac{m^2}{4}\cos\beta\right] M_e + O_e$$

$$R_b = \left[\frac{m^2-4}{12}\right] M_e + O_e$$

B—When the conductor is stranded and short-circuited at each half turn,—

$$R_t = \left[\frac{m^2-1}{3} + \frac{m^2}{4}\cos\beta\right] M_s + O_s$$

$$R_b = \left[\frac{m^2-1}{12}\right] M_s + O_s$$

C—For a continuous stranded coil, wound straight up,—

$$R = n^2\left[\frac{m^2-1}{12}\right] M_s + \left[\frac{m^2-1}{4}\right] M_e + O_e$$

D—For a turned over coil, continuous stranding,—

$$R_t = n^2 M_s\left[\frac{m^2-1}{3} + \frac{m^2}{4}\cos\beta - \frac{m^2-1}{16}\right] + \left[\frac{m^2-1}{16}\right] M_e + O_e$$

$$R_b = n^2 M_s\left[\frac{m^2-1}{12} - \frac{m^2-1}{16}\right] + \left[\frac{m^2-1}{16}\right] M_e + O_e$$

E—For a turned over coil—short-circuited at each full turn with two coils per slot,—

$$R_t = n^2 M_s\left[\frac{m^2-1}{3} + \frac{m^2}{4}\cos\beta - \frac{m^2-1}{12}\right] + \left[\frac{m^2-1}{12}\right] M_e + O_e$$

$$R_b = \left[\frac{m^2-1}{12}\right] M_e + O_e$$

F—For one coil per slot turned over and short-circuited at each turn,—

$$R = n^2 M_s\left[\frac{m^2-1}{3} - \frac{m^2-1}{12}\right] + \left[\frac{m^2-1}{12}\right] M_e + O_e$$

G—For one coil per slot turned over with continuous stranding, $R = M_s\left[\frac{s^2-1}{3}\right] + O_s$ (approx.)

Where

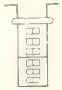
$$\alpha = \sqrt{\frac{0.4}{1 + 0.00427\,\theta}\,F r_1}$$

β = angular displacement between the conductor currents of the top and bottom slots.
F = frequency.
r_1 = ratio $\frac{\text{copper width}}{\text{slot width}}$
θ = total temperature of copper in deg. C. above 0° C.
r = ratio of total conductor length to embedded part.
m = number of conductors depthwise of the slot.
n = the number of strands depthwise per conductor.
s = total number of strands depthwise.
h = depth of strand in inches.
M_s = value from Fig. 5 corresponding to αh
f = depth of conductor in inches.
M_e = value from Fig. 5 corresponding to αf equivalent.
O_e = value from Fig. 6 corresponding to αf equivalent.

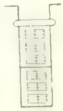
$\alpha f_e = \alpha f$ equivalent $= \alpha f\left[\frac{1}{n^2} + \frac{n^2-1}{n^2}\,\frac{1}{r^2}\right]$ = the equivalent depth solid conductor (Fig. 6.)

O_s = curve value from Fig. 6 corresponding to αh.

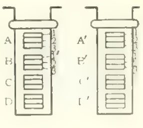
Class A—For two coils per slot, and one or more conductors per coil, each conductor consisting of a single strap in depth.



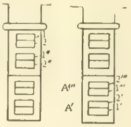
Class B—Similar to class A except that each conductor is composed of a number of strands in depth all in parallel. The coil is open on the front and back and the turns are joined together by connectors which short-circuit the strands in each conductor at each end of the conductor. This type of coil is formed in two parts and is used where the coil is too heavy to be handled in one piece or where the bore of the machine is too small to permit the complete coil being entered.



Class C—This is a practically absolete design. It is used in closed slot machines and covers a shoved through concentric type of winding. In such a coil the turns are wound continuously without a break, and the strands are connected together only at the beginning and end of the coil. The conductors and strands occur in the same order in the return slot as in the start. *A* at the top is followed by *B*, *C* and *D*, and hence the coil is wound straight up.

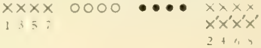


Class D—This is one of the most common types of coils, in which the turns in a coil are wound continuously and the coil lies in the top of one slot and the bottom of the other. These coils are turned over in making the loop at the ends, so that the top of the coil on one half becomes the bottom on the other half as illustrated. These coils may consist of any number of conductors and any number of strands per conductor, and the strands are kept separate, being only short-circuited at the beginning and end of the coil.

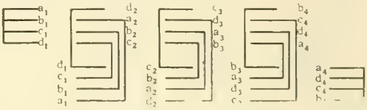


Class E—This coil is similar to class *D* except that at the end of each complete turn the strands are short-circuited by the connector joining one turn with the next. This coil is open on the front end and differs in this respect from class *D*, which is a closed coil. The eddy current factor for a transposed coil is calculated under class *E*. The transposed coil is used to give the effect of a multi-conductor coil without the disadvantage of high voltage between turns within the coil or the loss of space for conductor insulation.

In the transposed coil the strands per conductor must be a multiple of the slots per phase per pole. The strands are then separated into groups equal to the number of slots per pole per phase. The strands in a group are short-circuited by connectors which join them to a corresponding group in the next coil, in such a manner that if the positions of each group are followed through a phase belt, it will be found that all groups occupy all positions in the slot and the voltage generated by the slot cross flux is equal for all the groups in a phase belt. This arrangement is shown diagramatically below.



where the *x's* are coils in one phase belt of a three phase winding. For simplicity a one turn coil is shown and each group composed of one strand. The successive positions of a coil are shown as *1*, *2*, *3*, *4*, *5*, *6*, *7* and *8*, this being the sequence of conductors in series. Each single conductor is then arranged in four groups of strands, so that a section of the coil group would show as below.



Class F and G—The principle of these coils is the same as *E* and *D* except there is only one coil per slot.

Secondary Conductors for Electric Furnaces

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Electrical Engineer,
Halcomb Steel Company

When the old rocker-type Heroult furnaces were installed, the secondary leads extending from the transformers to the electrode holders were usually carried as shown in Fig. 2, with the section *EF* paralleling, and in close proximity to, the upright I-beams forming the mast of the furnace. In a six ton installation, the three 400 kv-a. transformers were arranged end to end, occupying a floor space of 23 ft. by 4 ft. 6 in., and the total linear length of single conductor from transformers to electrode holders was 49 ft. Each bus conductor was composed of six 6 by ¼ inch copper bars and there were stranded cables in each phase. The maximum possible average power which could be introduced into the furnace was 1100 kv-a. and, therefore, the melting period was somewhat prolonged and production was correspondingly reduced. The power-factor was only about 80 percent under the most favorable conditions.

In order to increase the production of steel it was decided to reduce the length of the leads, design the conductors so as to reduce the reactance and thereby improve the operating power-factor. Because of the success of this new installation, it would appear desirable, as well as profitable, if all of the existing installations of the old type could be remodelled somewhat along similar lines.

In the particular installation under discussion, the primary voltage of the transformers is 11 000 and, in order to eliminate the exposed, overhead, high-tension conductors which had been a source of danger, the conductors leading to each transformer are composed of two 2-conductor No. 2 B. & S. varnished cambric lead encased cables. The cables are enclosed in three inch sherardized conduit and immediately above the transformer bushings the cables are brought out through cable terminals Fig. 3. The opposite ends of the cables are suitably terminated on a specially designed tap-changing switch, interlocked with the circuit breaker so that when operating on one voltage, one set of taps is used, and when using another voltage a different set of taps is used. On account of the small potential difference between adjacent taps, the conductors can be carried through the same cable terminal and transformer bushings, thereby improving the appearance of the construction work.

The transformers were re-arranged so that their sides are adjacent, thereby making a more compact grouping and reducing the above dimensions to 14 ft. 9 in. by 6 ft. 10 in. This shortens the linear length of bus conductor forming the delta by approximately ten feet, and allows a more symmetrical arrangement of the delta, Fig. 4, which is formed over the top of the transformers.

From the delta connection the three conductors, each composed of six 6 by ¼ in. bus-bars, rise at an angle of 80 degrees from the horizontal so that, after passing through a dividing wall, Fig. 3, they are high enough to allow the flexible cables to be adjusted for proper clearance above the furnace floor.

The bus-bars, after passing into the insulated boxed opening in the dividing wall, are spread apart to enable connector terminals to be bolted thereon, Fig. 5. The cable terminals are of the solderless type, Fig. 6, made especially for this installation, and have shown no sign of heating since their installation about a year ago.

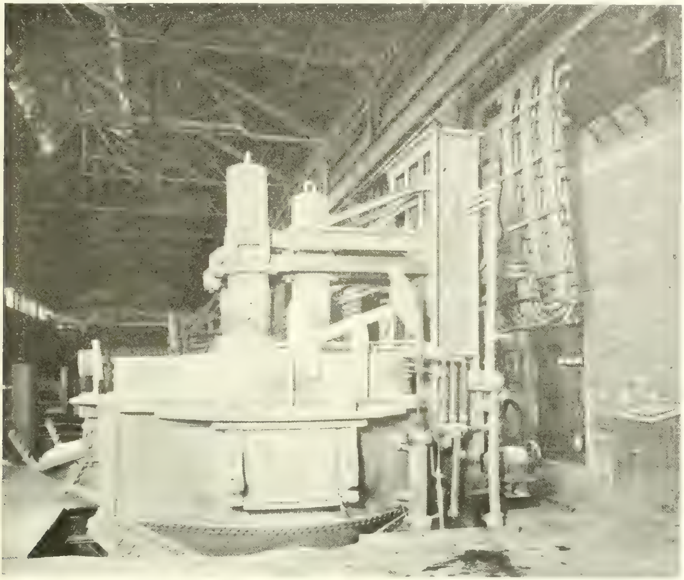

FIG. 1—SIX TON HEROULT FURNACE

In order that the distribution of current in the copper bars used for conductors may be as uniform as possible with the least temperature rise of the bars themselves, particular attention must be given to bus-bar sizes and spacings, as well as their relation to each other. It is generally advisable to use as few bars in parallel per phase as possible, although too large a cross-section will allow the magnetic field to set up differences of potential between different sections of the conductor, thus causing eddy currents in the copper. A magnetic field is produced inside and outside of the conductor, and the closed lines of magnetic force which are generated on the inside of the conductor produce electromotive forces only in their interior. This counter electromotive force of self-induction is largest, therefore, at the axis or interior of the conductor and is least at the surface, so that the current density will be greater at the surface of the conductor. In wide bus-bars, the current density will be greater toward the edges of the bars, thus producing extra heating at these points; however, on account of the high heat conductivity of copper, this increased heat at the edges is conducted toward the center and radiated at a comparatively small increase in temperature over that produced if the current were uniformly distributed over the bar.

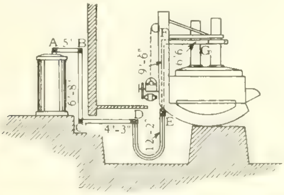

FIG. 2—ORIGINAL ARRANGEMENT OF FURNACE LEADS

As the frequency in this installation is 25 cycles, the individual bus-bars were not interlaced after leaving the transformers and, as the spacing between phases was kept rather large, it was economical to use six bus-bars in parallel. Ordinarily bus-bars should not exceed ⅜ in. thickness for 25 cycles or 5/16 in. for 60 cycles and in this instance ¼ in. was selected as the proper thickness. The spacing between bars was made ¼ in. and copper strips 6 by 1 by ¼ in. were cut from the same bus-bar to serve as spacers between bars. These were used in preference to an insulating material, as much better results have been secured with this practice.

As will be noted from Fig. 1, the same method of carrying the bus-bars under the gallows was adopted as in the original installation, as the length of conductor necessary is thereby much shorter than is the case where all busses pass over the top of the masts as in the latest type Heroult installations. To offset the objection of not having enough clearance between flexible cables and floor, the cables are supported at a distance of 4 ft., 4 in. from the dividing wall, Fig. 6, thus throwing the loop of the cables over the top of the winches on the furnace.

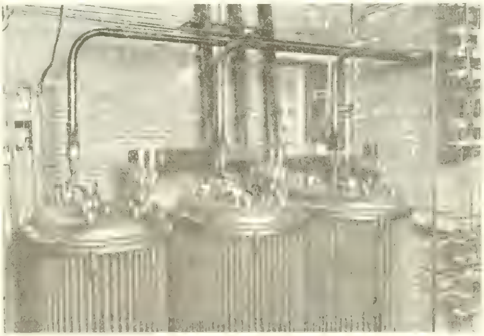

FIG. 3—TRANSFORMERS AND BUS-BAR STRUCTURE

The bus-bars, before passing through the I-beam masts, are spread to enable an insulating box to be inserted so that the stranded winch cable for raising and lowering the gallows may pass through. Details of this construction, with the solderless connectors for terminating the lower end of the flexible cables, are shown in Fig. 6.

The bus-bars after passing underneath the gallows are not carried as a solid section directly to the electrode holders and bolted thereto, as this method required an entirely new bus section being installed under the gallows whenever an electrode holder was changed, since the ends of the busses become welded into the milled slots of the electrode holder. By the new method the ends of the bars are slotted as in Fig. 6, allowing adjustment of the holders, which would be impossible with the old type of construction. A short 12 in. section of bus is then inserted between the holder and the end of the main bus, Fig. 7, one end being bolted to the holder and the other end to the main bus. When changing a holder, all that is necessary is to replace this 12 in. section of bus (6 ft. for one phase) instead of the complete section under the gallows 6 ft. 6 in. long (length of one phase, 39 ft.) producing a saving of 33 ft. of bus-bar. At the base of the milled slots in the holder, hack saw slots are cut to allow greater flexibility of the fingers when bolting on the bus bars.

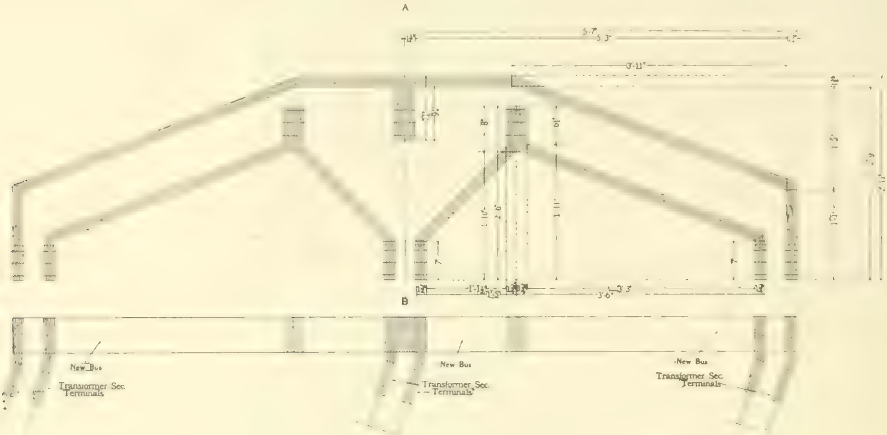
A
B
5'-7"
3'-11"
3'-6"
New Bus
Transformer Sec. Terminals
New Bus
Transformer Sec. Terminals
New Bus
Transformer Sec. Terminals

FIG. 4—DETAILS OF DELTA CONNECTIONS OF THE TRANSFORMERS

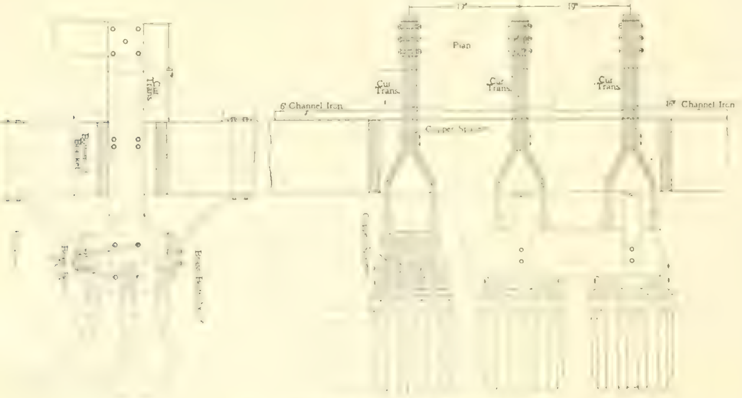

FIG. 5—CONNECTIONS OF THE BUS BARS

FLEXIBLE CABLES

In using flexible cables for conducting power to electric furnaces, special attention must be given to "skin effect" and losses resulting therefrom. In meeting the requirements of electrical service, however, mechanical considerations must not be neglected, as particular attention must be given to supporting the weight of the cables, spacing and placing them so that when the furnace is tilted, the supporting members will fulfill their function properly without distortion. The strands of the cables must not be subjected to individual strain, which would break or twist them.

As mentioned before, in carrying heavy currents to electric furnaces the outer portion of a current carrying member has, by far, the greatest current density. Since the flexible leads form about 40 percent of the total length of conductor between transformers and electrode holders, an excellent opportunity exists for adjusting the reactance and thereby reducing the skin effect. It is well known, of course, that stranded conductors offer somewhat better conditions, especially if the individual strands forming the cable are in poor contact with each other. This being the case it appeared desirable to build a flexible cable, wherein all members of the conductor are caused to average the same position throughout the total length, and have the same resistance. In this way all paths for the passage of current are practically equal, the impedance of each conductor member will be the same and, therefore, a uniform current distribution throughout the entire cable will result.

The flexible cable is of 1 000 000 circ. mil capacity and is 1.5 inch in diameter. It is built up with the first strand composed of seven No. 24 B. & S. gauge wires, seven of these strands forming a braid, seven braids forming a still larger braid, and seven of the largest braids forming the final cable, all rope laid. A cable, therefore, is composed of 2401 No. 24 wires and each wire is thoroughly shellaced to insulate it as much as possible from adjacent wires. By using many small wires not only is greater flexibility secured, but due to the immense wire surface (151.62 in.) skin effect losses have been practically eliminated.

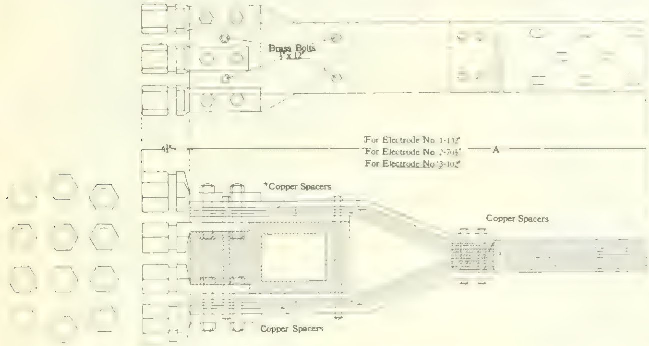

FIG. 6—CABLE TERMINALS

The flexible cables, Fig. 11, are grouped in proper phase relation and pass over the top of three half-round maple drums, which are grooved. Twelve cables form each phase, the conductors of the top layer being 16 ft. 4¾ in. long; the middle layer 16 ft. 3 in. long and the bottom layer 16 ft. 2 in. long. Proper clearances are provided by bolting two-piece solid maple yoke spreaders to the cables; also the individual cables of opposite phases are held rigidly against mechanical movement caused by the magnetic forces. The two bottom sets of spreaders are split up into individual phase units, Fig. 10, so that electrodes may operate at different heights. The projecting ends of these spreaders strike each other with any cable movement, thus effectually preventing short-circuits between phases.

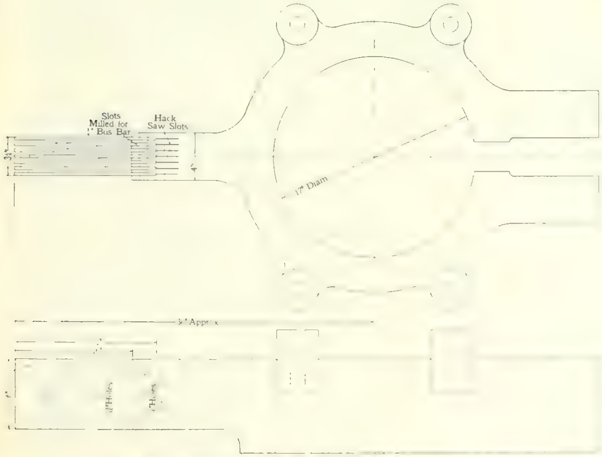

FIG. 7—CONNECTIONS TO ELECTRODE HOLDER

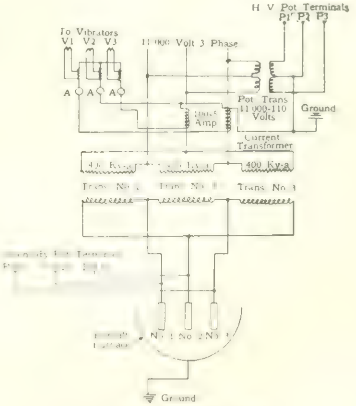

FIG. 8— TEST CONNECTIONS

REACTANCE

On account of satisfactory reactance obtained, it was not considered necessary, in view of the expense, to raise the transformers to a higher elevation. Had this been done the linear length could have been reduced 12 feet. The length of conductor from the transformers to the electrode holders, as actually installed, was reduced approximately 20 percent from the older method illustrated in Fig. 2. This percentage would, of course, be increased to nearly 50 percent if the transformers were raised.

The inherent reactance of the transformers is 12 percent, and the conductors were designed so that the total overall reactance of transformers, bus-bars, flexibles, electrodes and furnace would be 43.6 percent which allowed 90 percent operating power-factor to be attained and a short-circuit current of 229 percent.

Oscillograph tests were made to confirm the estimated maximum possible short-circuit currents in the different phases. Fig. 8 indicates the method of connecting the oscillograph for the tests. Fig. 12(b) is an oscillogram of the current waves in each phase with the electrodes short-circuited in the bath of steel. The highest current values attained were:—

Vibrator 1	179.2 amps. effective
Vibrator 2	218.0 amps. effective
Vibrator 3	181.2 amps. effective

From the above, an average effective current of 192 amperes is secured, indicating an approximate short-circuit current of 274 percent actual, as against 229 percent as estimated.

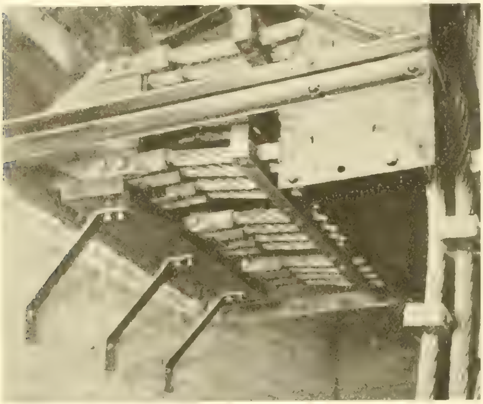
FIG. 9—TOP SECTION OF FLEXIBLE CABLE SUPPORT

Fig. 12(a) is an oscillogram of the current waves with the electrodes short-circuited on the cold steel scrap, taken with a slower film speed. The highest current values attained were:—

Vibrator 1	126 amps. effective
Vibrator 2	146 amps. effective
Vibrator 3	137 amps. effective

From the above an average short-circuit current of 195 percent is indicated. This is somewhat lower than in the first test, because a poorer contact was made between the electrodes and the scrap, and the resistance of the scrap is higher than that of the molten metal.

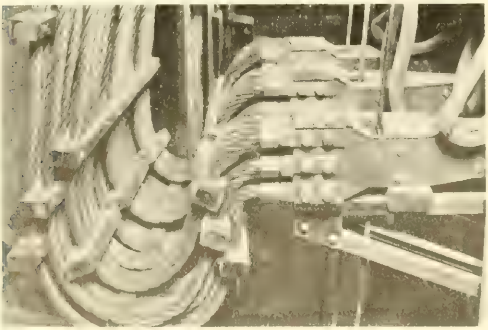
FIG. 10—[illegible] END OF FLEXIBLE CABLES

Fig. 12(c) is an oscillogram of the primary voltage waves with 1500 kw load.

Vibrator 1	Volts phase 2 to 3
Vibrator 2	Volts phase 1 to 2
Vibrator 3	Volts phase 1 to 3

Fig. 12(d) is an oscillogram of the secondary voltage waves with 1500 kw load.

Vibrator 1	Volts No 3 electrode to ground
Vibrator 2	Volts No. 2 electrode to ground
Vibrator 3	Volts No. 1 electrode to ground

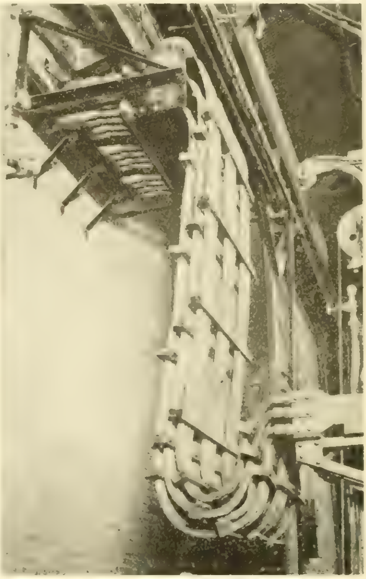
FIG. 11—GROUPING OF FLEXIBLE CABLES

In the above oscillograms evidence is obtained of high frequency disturbances, between 7000 and 8000 cycles, caused by the arcs in the furnace. Partial rectification of current is also indicated.

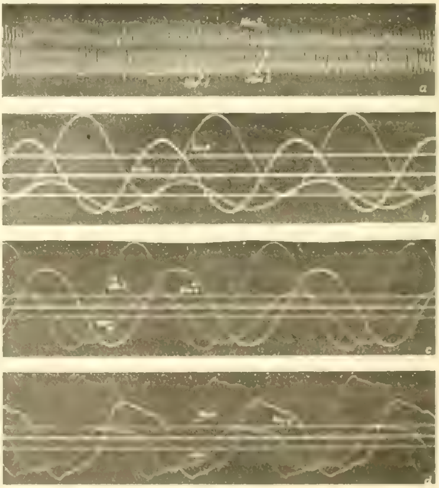

FIG. 12—a, b, c, d—OSCILLOGRAMS OF FURNACE CHARACTERISTICS

The operating performance of this furnace, since the new installation was made, has been much improved, as the melting periods have been reduced approximately twenty minutes. This means an increased monthly output of approximately seven tons. The current cost has been reduced 50 cents per ton, which means a monthly reduction for power of $275. Based on these figures the present cost of doing the work could be met in six months.

There are numerous other ways of attacking the problem under consideration, in fact, there will be many cases where it will be highly desirable to install external reactances of either the air or iron core type. The disadvantages of the present types are too well known to be enumerated here, and it is hardly necessary to point out the advantages that would be obtained from a reactor which would have say, 25 percent reactance at normal current and 75 percent reactance at 200 percent normal current. Not only would increased protection be obtained on overloads but higher power-factor under normal conditions. This matter is being given careful attention by a number of investigators and will doubtless lead to important results in the near future.

THE JOURNAL QUESTION BOX

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To receive prompt attention a self-addressed, stamped envelope should accompany each query. All data necessary for a complete understanding of the problem should be furnished. A personal reply is mailed to each questioner as soon as the necessary information is available; however, as each queston is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply.

1012—BURNED SPOTS ON COMMUTATOR—A 25 hp, 220 volt direct-current, two-speed elevator motor has developed four black spaces, three segments wide, equally divided around the commutator. The motor has four main poles and four commutating poles and is compound wound. The brushes are placed opposite the main poles, is this the right position? The controller for this motor is equipped with a dynamic brake. When running there is little or no sparking at the brushes except when changing from high to low speed there is a little sparking noticeable. If the commutator is cleaned and then run for 5 or 10 minutes these four black spaces will show up again. This trouble developed, or was first noticeable a few days after the armature was installed. What causes these black spaces. S.L. (N.Y.)

The correct position with respect to the main poles of the brushes on the commutator varies with the throw of the leads from the slots to the commutator. If the lead from the armature coil lying half way between the main pole tips is traced to a commutator bar, this bar should be covered by a brush. In many motors this brush position would be opposite the main pole. The data given is not sufficiently complete to definitely state the primary cause of the burned spots on the commutator. The spots are caused by sparking which probably is only under the brushes and so not visible. This sparking may be the result of various things. It is possible that the armature has a winding that in some way is not symmetrical, as when there is an idle bar in the commutator. This might cause sparking at four equidistant points on the commutator. If, through any accident the commutator became roughened at one spot, sparking would commence there. The most of the current would then be diverted and pass through the brush on the opposite side of the commutator. If the brushholder rigging is not rigid when these two spots come underneath two sets of brushholders it may cause the brush rigging to vibrate, causing sparking at the other two sets of brushes. This sparking then in turn would cause two more black spots on the commutator, all four black spots being equally spaced. Cleaning the commutator with sandpaper, even if the only trouble is commutator roughness, does not now eliminate the trouble as the spots have caused the commutator to be no longer true and sandpapering only does not true it, but probably leaves mica projected at the location of the spots. This then immediately causes spots again when running is resumed. The commutator should be trued, and the mica undercut. If this does not cure the trouble, the armature winding is in some way unsymmetrical. See also question 1508, June '18; 886, April 1913 and 455, June 1910. S.H.

1013—WELDED LAMINATIONS—Due to a burn out a part of the laminations of a number of the teeth are welded together in a stator. Will this give any trouble when the motor is rewound? W.R.V. (GA.)

Welding together the laminations will produce a local short-circuit path for eddy currents, which will greatly increase the temperature at that point and will increase the losses of the motor. The amount of these losses will depend on the extent of the welding. While a small amount of welding will probably not produce prohibitive losses, it is much better either to separate the laminations at the welded part, or to replace them, inasmuch as this local heating or hot spot will probably injure the insulation and cause the motor to burn out again. T.P.K.

1014—OILING SYSTEM OF VERTICAL WATER-WHEEL ALTERNATOR—On certain vertical water-wheel generators the oil passes from the upper guide bearing through a pipe in the lugs of the rotor. The lower guide bearing is supplied by a separate oil pipe. Does the oil from the upper guide bearing also flow through the lower guide bearing and act as a lubricant in addition to that supplied by the lower bearing feed pipe in the usual design, or is the oil supplied to the upper guide bearing used only in this bearing? If the oiling devices are in good condition, should any oil run down the shaft of a vertical unit while it is at a standstill, or are the oil deflectors or oil catchers only supposed to properly handle the oil from the guide bearings when the shaft is revolving? R.B.G. (MONT.)

A slight amount of the oil that passes through the upper guide bearing may pass through the lower guide bearing but when this bearing is fed by a separate pipe line it receives sufficient oil from the latter source. Under no conditions should any appreciable amount of oil find its way down the shaft. R.A.M.

1015—STATOR WINDING TESTS—We have a Portable Testing Transformer rated 5 kv-a, 220-210-200-110 and 10 000 volts, 25 cycles. This outfit is used in testing our rewound stators for grounds and short-circuits between phases. The circuit breaker in the primary side is set to trip at four amperes. It was our custom to impress the testing voltage (which is usually 1500 volts) across the several phases to ascertain if same were not open circuited before giving the stator a low voltage balance test. This procedure was criticised by several of my associates, they claiming that the windings are liable to be broken down between turns, of the individual coils. My contention is that the ohmic resistance of the stators are usually so extremely low, that the instant the voltage is applied to the terminals of one phase, the voltage falls so rapidly that a puncture of the insulation between adjacent groups could not possibly happen; also taking into account the high reactance of the testing transformer and the low tripping value at which the breaker is set. Please let me have your comments. F.R.D. (N.Y.)

The reactance factor of the stator winding should be considered as well as the ohmic resistance. A lighting out circuit on 110 or 220 volts with one or more lamps in series would be a more desirable way of testing for open circuits. 1500 volts is rather a high test voltage for 110 or 220 volt windings. G.A.B.

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

SEPTEMBER 1920

Field Winding Diagrams for Railway Motors—III.

Field Control Motors

The most common method of control used on railway equipment is the series-parallel rheostatic control. On a quadruple equipment using this type of control the general operation is as follows:—

No. 1 and 3 motors in parallel, in series with No. 2 and 4 motors in parallel, in series with all resistance.

Several notches cutting out part of the resistance at each step.

All resistance out — the series-parallel running position.

Transition step.

No. 1 and 3 motors in parallel, in parallel with No. 2 and 4 motors in parallel, in series with all resistance.

Several notches cutting out part of resistance at each step.

All resistance cut out, full parallel running position.

With field control, there is an additional step after the full parallel running position, which cuts out some of the main field coil turns on each coil of all the motors. This weakens the motor field and speeds up the armature, giving an extra high speed running point. This is the most common method used for field control. The same effect is sometimes obtained on locomotive equipment by using an inductively wound coil in parallel with the main field coils, so that when the switch in this shunted coil is closed, part of the armature current is shunted from the field coils, which weakens the field, and speeds up the armature.

DESIRABILITY OF FIELD CONTROL

In the selection of gear ratios, accelerating currents are kept low and motor temperatures are reduced by the use of the smallest possible number of teeth on the pinion, with a consequent saving of power and reduced maintenance of equipment. However, the free running speed of the car is thereby reduced to a minimum. Using a larger number of teeth in the pinion to produce the desired maximum free running speed of the car gives higher accelerating currents and increased motor temperatures, with greater power consumption and increased maintenance of equipment. By taking advantage of the increased speed obtained by weakening the motor field, while still retaining the small pinion, it is possible to get the high free running speed characteristics obtained by the use of the large pinion, combined with the low accelerating currents and consequent advantages of the small pinion.

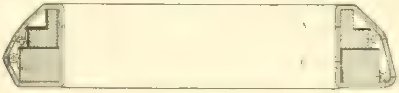


FIG. 10—SECTION THROUGH MAIN FIELD COIL

FIELD CONTROL COILS

In Fig. 10, the assembled coil consists of two separate coils (short or permanent coil *B* and added coil *A*), assembled together and having four leads. Generally, the short or permanent coil has 60 percent of the total number of turns, while the added coil has the remaining 40 percent. As the added coils are worked only a part of the time, the section of the copper conductor in this coil is made smaller, approximately 75 percent of the section used on the short or permanent coil. This arrangement allows more space for the winding. All four coils are usually wound symmetrically with the same number of turns; however, there are some few exceptions where the top and bottom coils have more turns than the two side coils.

TYPICAL FIELD CONTROL WINDING DIAGRAM

In Fig. 5, June R. O. D., a schematic diagram is shown of a field control motor. In Fig. 11 a typical field control motor diagram is shown which plainly distinguishes between the short or permanent field winding and the added field winding. It is of the utmost importance to have the motor correctly connected to the car wiring. For the high free running speed it is essential that the added field F_m to $F-$—is cut out and not the short or permanent field F_m to $F+$. This has happened where all four motors had the wrong connections and were placed in service, with a resulting dangerously increased speed and the final roasting of the F_m to $F-$—added coils, which have the reduced section of copper. If this wrong connection should be made to only one motor, this motor would carry an excess load and roast out its field and armature windings.

In order to get the desired results for which this type of motor is designed, carefully note the following:—

1—See that the connections are as shown on the diagram.

2—Be sure that the connections are such that the added coils F_m to $F-$—are cut out for the high speed running.

3—Check the polarity of the short or permanent coils $F+$ to F_m, also of the added coils F_m *to* $F-$. (See R. O. D.—Dec., 1916)

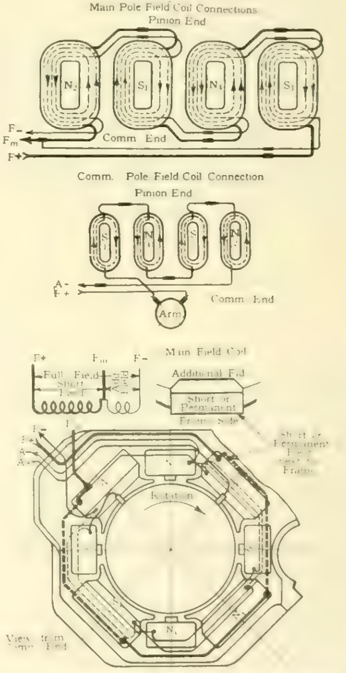


FIG. 11—CONNECTIONS OF FIELD CONTROL MOTOR

Dotted lines show connections at pinion end.

4—Note the location of the short or permanent coil leads $F+$ to F_m and see that they come from the assembled coils as shown on the winding diagram, which in some motors is next to the frame and in others next to the armature.

5—Note the location of the added coil leads F_m to $F-$—and see that they come from the assembled coils as shown on the winding diagram, which on some motors is next to the frame and others next to the armature.

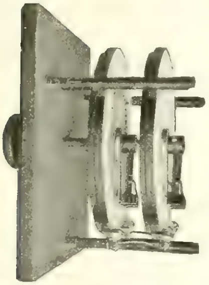
6—It is not feasible to try to locate these coils by checking their resistance as these values are misleading. One example is as follows: Short or permanent field coils measure 0.1407 ohms, added field coils measure 0.1499 ohms. This is due to the difference in copper section of the two coils.

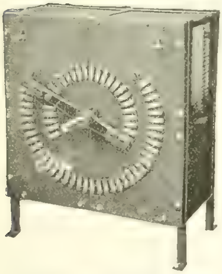
J. S. DEAN.

Ward Leonard

Resistors and Field Rheostats

Enameled Field Rheostat For Mounting on Front of Switchboard.


Enameled Field Rheostat For Mounting on Back of Switchboard.

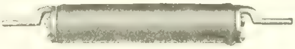

Remote Control Field Rheostat

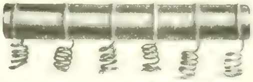
Ward Leonard Vitrohm Resistors are made in a great variety of sizes and types—a number of which have never been made by other manufactures, because there is no equivalent to Ward Leonard Vitrohm or Ward Leonard manufacturing processes. The vitreous enamelled insulation used on all Ward Leonard Resistors insures protection to the resistance element against atmospheric conditions.

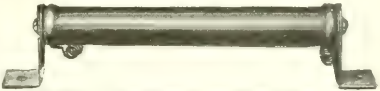
Ward Leonard Field Rheostats of all sizes, in both round and rectangular types, have the resistance element embedded in and protected by Vitrohm—vitreous enamelled insulation. Therefore, heat, cold acids, alkalies, oils, etc., cannot attact resistance elements. This construction eliminates any mechanical strain on the resistance proper, and as no combustible material is employed, these rheostats can be used wherever desirable.

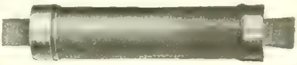
We will gladly send you free a sample 3,000 ohm unit so you can see how impervious Vitrohm insulation is.

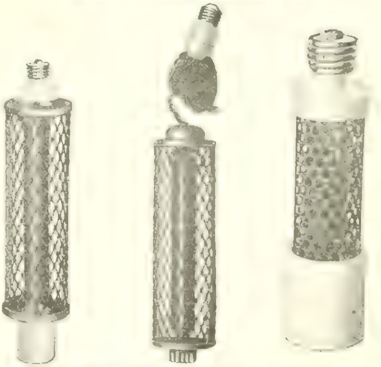
Resistance [illegible] ferrule ends and slip into fuse clips on the rack.




Vitrohm Resistor Unit of any capacity can be provided with any style or number of terminal connections.


Resistors for switchboard mounting—clips on ends provide for fastening to the board and connecting them or for slipping into knife terminals.




Vitrohm Resistor Unit for [illegible]

Ward Leonard Electric Company

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Vernon,
New York

Westburg Engineering Co., Chicago
Walter W. Gaskill, Boston
Wm. Miller Tompkins, Philadelphia
Sperry & Bittner, Pittsburgh

Electric Material Co., San Francisco
Walter P. Ambos Co., Cleveland
Electrical Specialties Co., Detroit
Lyman C. Reed, New Orleans

THE MAKING OF OXYGEN HYDROGEN GAS GENERATORS.

Fifteen years is not a very long time in this fast moving age, and yet it is long enough to take the world back to the time when oxygen and hydrogen were little known industrially and commercially in this country. Today these important gases have revolutionized manufacturing. Repair work has been put on a different plane. Salvaging has become a dignified and profitable occupation. In fact, the industrial application of oxygen and hydrogen are so numerous and diverse that its possible future importance can only be measured by its rapid development in the past few years. No method for obtaining oxygen and hydrogen has proven more satisfactory than that of decomposing water by means of the electric current into its component parts. This is one of the oldest electric-chemical processes and engineers have given their constant efforts toward the perfection of such apparatus. Beginning back in 1909 Mr. Levin, inventor of the Levin cell, spent a year and a half in the investigation of the electrolytic cells and special application of the oxygen-hydrogen flame, and the Levin cell is the outcome of long engineering experience. Mr. Levin has been connected with international developments of the oxygen-hydrogen gas generator. The Electrolabs Company and the Electrolytic oxy-hydrogen Laboratories are devoted exclusively to the oxy-hydrogen industry, the former in the capacity of manufacturing and sales organization, and the latter as research and development for the apparatus and application of oxygen and hydrogen gases. The research and development have resulted in extensive patents covering the pure science phase, as well as the manufacturing aspects of the industry. Their research in over voltage and other refinements has resulted in the first basic patents in the art. The generating boxes are filled with a strong caustic solution through which the direct electric current is permitted to pass. The oxygen is formed in the oxygen compartments on the positive pole and the hydrogen is formed in the hydrogen compartments on the negative pole. The gases from each are collected in independent manifolds or offtake pipes and conserved in regulation gas holders. The cells are built in two sizes—Type "A" and Type "B". Both cells are made exactly alike except that they are of different dimensions. The production of gases in each type is directly proportional to the number of amperes passing through it. Each cell is of the unit type. It is small and compact, also simple in construction, being enclosed in stamped sheet metal sections. They have found American "Ingot" Iron Sheets, as a result of [illegible] extended tests to be by far the most [illegible] material for the construction of their apparatus.

The electrical problems are best taken care of by Ingot Iron because of the exceptionally high electrical conductivity of this metal. By the use of this pure iron the portions coming in contact with oxygen generated in the machine and the actual surfaces on which the oxygen is generated have the ability to retard corrosive action to a marked degree. The welding of the machines has become a very simple problem in various ways, due to the high purity and uniformity of ingot iron steets and wire, thus devloping highest efficiency and economy.

DATA SHEET SERVICE SOLVES BRUSH PROBLEMS.

The National Carbon Company of Cleveland and San Francisco has recently increased the scope and efficiency of the Columbia Data Sheet Service for users of motors and generators so that they may now be assured of absolutely correct brushes for these machines.

The data sheet furnished has twenty blank spaces in which the user indicates whether the brushes are needed for a generator, motor or rotary converter, also the service for which it is used, whether the current is direct or alternating, the name of the manufacturer, the type and serial number of the machine, voltage, capacity, load, measurements and so on.

From these data in connection with exhaustive laboratory tests it is possible for the National Carbon Company to furnish Columbia Pyramid Brushes best suited for the exact operating conditions. Through this service of investigation, analysis and specification, it is possible to guarantee satisfaction with these brushes. The service is at the command of any user, no matter how many or how few units he has.

NEW BOOKS

"Automobile and Gasoline Engine Encyclopedia"—A. L. Dyke—900 pages—3392 illustrations. Published by A. L. Dyke St. Louis, Missouri. Price $6.00.

This is the twelfth edition of this well-known encyclopedia which has become generally recognized as the most complete reference work on automobiles so far published. In fact, if one has this book available there is very little necessity for purchasing any other book on this subject. The text is much the same as in previous editions but modifications have been made to bring the material up-to-date and in keeping with developments and changes in automobile manufacture. While this book is, of course, valuable as a means of furnishing the beginner with a knowledge of motor construction, it is probably more useful as an instruction book on repair work. There are 1189 illustrations and 154 pages devoted to repair work alone. A very complete section is given on the electrical end of automobile practice. This section includes 270 pages with 775 illustrations, showing various forms of electric starting, generating and lighting outfits, as well as various types of ignition systems. Special attention is given to descriptions of some of the leading types of automobiles, in addition to general discussions on the subject and applying to any machine. Certainly any motorist who does his own repair work will make no mistake by purchasing this encyclopedia.

"Standard Electrical Dictionary"—T. O'Connor Sloane. 767 pages—477 illustrations—Published by Norman W. Henley Publishing Company, New York City. Price $5.00.

This is the 1920 edition of this dictionary which has been revised from time to time since originally brought out in 1892. A second part has been added to the original volume so that, at present, it is necessary to look in two portions of the book, as the classification is aphabetical. The second part includes discussions on topics which have arisen since the last edition appeared. Numerous illustrations are used to show details and to explain definitions. In some cases considerable space is devoted to explaining principles of operation and fundamentals of electrical engineering. Cross references are given where indicated, as a means of checking up on the use of technical expressions this book should be valuable as a reference.

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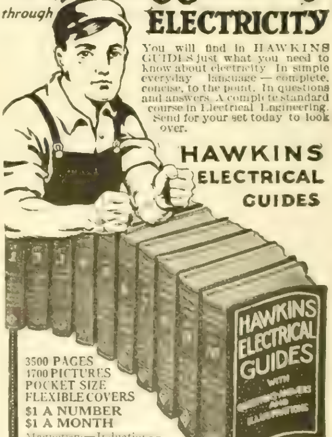

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THE ELECTRIC JOURNAL

VOL. XVII OCTOBER. 1920 NO. 10

The Electric Railway Situation

JOHN H. PARDEE

President

American Electric Railway Association

IN SPITE OF THE FACT that the showing of the electric railway industry of the country in the matter of income is still discouraging, I believe its prospects to be brighter than at any time since 1914, and this conclusion is based upon the very marked change in the public attitude. This is reflected in the action of legislatures, courts, commissions and city governments, in so far as they effect the railways. These bodies are fast coming to recognize what I believe to be the two fundamentals of the situation:—First, the essentiality of electric railway service; and second, the continuance for some indefinite time of the higher price level. It seems to me, that if there be a proper realization of these two facts, readjustment along lines which will benefit both the public and the railways is bound to follow.

JOHN H. PARDEE, President
J. G. White Management Corporation

The Federal Electric Railways Commission bases its entire series of conclusions upon the assumption that the electric railway is a necessary public utility, and a number of communities, such as Toledo, Bridgeport, the Borough of Richmond in Greater New York, Salem and other Massachusetts cities, have reached the same conclusion, not through any process of reasoning but by bitter experience derived from a trial of the motor bus without electric railway transportation.

With the essentiality of the service recognized, its preservation and continuance becomes a concern of the public, and I am confident that the public consideration of the methods by which this may be accomplished cannot but lead to public treatment which will establish utility credit in the only way in which this is possible, namely, through the provision of sufficient income to meet the reasonable demand of investors in public utility securities.

One of the many obstacles in the way of an earlier satisfactory readjustment has been the reluctance of both the regulatory authorities and the public to admit that the higher costs of railway operation were anything more than a temporary manifestation of war conditions, the disposition being to consider the present period of stress as merely ephemeral. For this reason it was the general disposition to withhold anything but emergency relief on the grounds that the necessity would soon pass and that so-called "normal" prices would shortly return. The popular conception of the price situation has, I think, changed. Men are realizing that any marked deflation would enormously increase the burden of the governments of the world in the matter of paying off their war debts and what the economists have long known is being brought home to the layman, namely, that price levels are slow in declining after major economic convulsions, such as the war.

A number of recent court decisions, notably those of the United States Supreme Court, in Lincoln Gas Company-vs-Lincoln; the United States District Court, in City of Winona-vs-Wisconsin, Minnesota Light & Power Company; and the New Jersey Supreme Court, in the Elizabethtown Gas Company case, emphasize these economic facts and the common sense of the American public is sure to eradicate the belief that the plight of the railways is merely the result of an emergency, and so increase the public willingness to come to a lasting settlement on correct lines.

The reception by the public of the report of the Federal Electric Railways Commission is evidence of the truth of my conclusion. There is a general acceptance of the Commission's recommendations by both the press and public authorities which indicates a much greater knowledge of the electric railway problem than existed when the Committee of One Hundred of the American Electric Railway Association began its attempt to bring the case of the electric railways before the public.

In spite of the disheartening conditions that still prevail in certain communities, there is, to my mind, much in the electric railway situation to bring encouragement to the industry.

Specifications of a Successful Street Railway

W. S. RUGG
Assistant to Vice-president,
Westinghouse Electric & Mfg. Company

A FRIEND, of whom I asked the question, "What is a successful street railway?", said, "There ain't no such animal." And there is a great deal of truth in that statement. I said to him, "If this is true, then there must of necessity be a lack of knowledge on the part of those engaged in the business, of what a successful street railway is, of what it consists, what is the foundation, the structure and the materials of which it is built. In other words, what constitute the essentials of a successful street railway?"

If the operating men, superintendents, presidents, stockholders, the people and their representatives, and the manufacturers, all knew and realized fully the essentials of what constitutes a successful street railway, we would have them. All desire them, and ignorance and the lethargy coming out of ignorance may be the reason we do not have them. My friend, then, being of an engineering type of mind, said, "Let us make out a specification of a successful street railway. Let us see what is necessary; maybe we can have one some time." The following is the result:—

1—A sufficient number of people who wish to ride instead of to walk, and who are willing to pay for such service.

2—City officers who appreciate that the people wish to ride and are willing to pay for the service, and who will insist that adequate service and adequate compensation to to the railways be provided. City and state authorities who appreciate that a street railway is for the maximum service to the people at least cost, and who will, therefore, see that the road is not burdened with taxes, paving, franchise charges and graft in any form.

3—A sufficient amount of track so distributed and built as to render maximum service to the public with maximum comfort and at least expense.

4—Overhead lines which are so built as to give adequate distribution of power with the least interference with the appearance of the streets.

5—Cars, clean, comfortable and pleasing to ride in, and of the proper size and frequency to give the best service to the people at the least expense.

6—Men to operate the cars and the railway who feel that their job is to render the best service to the people who ride; namely, the customers of the company.

7—Management to guide the operation of the road, who feel that they are representatives of the stockholders, and that they have something to sell; that the operation of a street railway is a service to the people, and that they can only discharge their duties to the stockholders to the maximum by giving the maximum possible service to the people.

8—A board of directors (who are chosen by the stockholders) who appreciate the above requirements and see to it that the officers of the company are men who carry out these principles.

9—An appreciation on the part of all the above,—people, city authorities, men, officers of the company, and the board of directors, of the fact that the street railway is a community service to such an extent that they all become stockholders so that a very considerable part of the capital invested in the business comes from those served and those serving.

All will agree that a street railway operating under the above conditions would be of necessity successful. The people would be willing to pay high enough fares for the service they desire, pay the men sufficient to insure their living well, reward faithful officers liberally, provide adequate equipment, and pay regular and liberal dividends. The men would not strike. Capital would anxiously seek investment in street railways. The best of equipment would be provided. The whole community would be proud of their road. The end would be a wedding of capital and labor, and they would live happily ever after and raise up a large family of satisfied customers.

The above is like any engineering specification, somewhat formal and inflexible. Those of us who have been looking at the street railway industry from a little distance, believe that we see the dawn of a new era. No other country in the world approaches us in electric railway development. This is very largely due to the vision and ability of our street railway executives, both in the past and the present. A wrong attitude of mind toward this industry on the part of the people and their city, state and national representatives, as well as labor, has been the one big obstacle to progress in the past. Our present railway executives recognize this and are rapidly doing their part toward overcoming this condition.

The Future of the Autobus as it Affects the Electric Railway

L. H. PALMER
Assistant to President,
The United Railways & Electric Co. of Baltimore

EVER since the internal combustion engine has been successfully adapted to private automobiles, passenger carrying busses have been equipped with this engine for transporting passengers for hire. The autobus has gradually eliminated the old horse drawn omnibus with which most of us were familiar. Gradually too the autobus came in some places, into competition with electric railways, as in carrying passengers from steam railroad termini to special objectives, such as hotels or pleasure resorts. During the slump in business which occurred at the beginning of the World War, when a large number of people were without employment, the jitney bus craze sprang up and spread from coast to coast, and has been a source of annoyance and loss of revenue to many street railways in one form or other ever since. At present this situation seems somewhat to have "shaken down" and we are beginning to see the real place of the autobus in the transportation field.

The busses, when operated as they are in England, notably in London, and some places on the Continent, have been able to supply transportation for local situations and short haul business. In New York City the Fifth Avenue Coach Company, with one of the best traffic routes in the world, has been able successfully to operate an efficient and noteworthy service. It should be observed however, that in London and Paris, as well as in New York, rapid transit lines running on private rights of way, and usually at high speeds are in operation and because of their unimpeded movement and greater carrying capacity with less frequent stops, have been able to care for the heavier loads, leaving what might be called incidental and sight seeing business, as well as the short haul riding largely to the motor busses and surface cars.

In cities where elevated or subway systems do not exist, the surface cars take the place of the rapid transit lines and carry the great bulk of the citizens from their homes to work and back in large capacity units to which, frequently, trailers are coupled for rush hour business. Certainly as far as the situation has developed in the United States, there is no autobus operation that has given promise, or shown any evidence of being able to handle the American rush hour business so efficiently as the street cars. In fact, as far as we can see, busses would be utterly unable to do so at a reasonable fare and without completely congesting the important thoroughfares in the business districts. If for no other reason, the limitation of carrying capacity, due to their size, restricts their adaptability to this character of service. It is not true then that if autobusses cannot carry the rush hour traffic, they should not be allowed to handle the non-rush hour traffic? For the electric railways the rush hour business is not the profitable business. On the contrary, the cost of handling the rush hour service, taking into account the investment necessary for cars, power and car house capacity which is used, and useful only for five or six hours per day, cannot be supplied on the present street railway fares. In smaller communities where the rush hour condition is not so acute, it might be possible to handle the city traffic with motor busses, but here the efficiency and traffic possibilities of the safety car furnish a solution which the motor bus cannot meet economically.

To serve small communities developing in outlying territory not far from cities having street railway service, or between towns separated by distances up to say, 50 miles, autobusses can well be used and later if it is found that they have built up traffic sufficiently a street railway line can be put in. Where autobusses can be used in such service they should logically be operated by the local street railway company, because the street railway organization has the training and the experience necessary to operate them regularly and efficiently, and can arrange for proper connections and schedules, and in some instances transfer privileges, where the length of ride is short enough to justify it. Under the control of an established and recognized company, their operation cannot help benefitting by the experience of such a company, and therefore be more dependable and render better service.

It is not clear how a motor bus can charge fares less than the street cars and carry people for equivalent distances. We have heard a great deal about the conditions in the city of Bridgeport, where the jitney busses on short runs through thickly populated territory have successfully competed with the street railway and now the latter has stopped operation, but this is a special condition and not general in its application. Already the efficiency of operation there is beginning to decrease and the public and merchants are awakening to the fact that the street car service has not been adequately replaced. Moreover, it is now summer, with favorable weather and street conditions, so that, even though the substituted service may appear somewhat satisfactory, it will take months to tell the story and it is a serious question whether the permanent handling of Bridgeport's traffic with motor vehicles will prove successful. Surely the experience of Toledo, with its month long traffic agony caused by "car-less" streets and irresponsible jitney-cluttered highways, ought to point a lesson that should not be ignored.

At present most electric railways are grossly and unfairly overtaxed for street paving, construction and maintenance. The autobus has never paid an adequate amount for road and highway maintenance. Some day the state, county and municipal authorities will awake to the seriousness of this situation and impose sufficient taxes on the road users, who cause road damage and excessive wear. When this unjust situation as to excessive tax burdens on electric railways and under taxation on motor vehicles is righted, and other forms of taxation are equitably applied, the present advantage of the autobus will disappear and a handicap to the electric transportation industry will be removed.

With these premises and conditions in mind the future of the autobus lies in its adaptability to supplementary and auxiliary service. The flexibility of motor busses is obvious and admitted. The constant improvement in the character of highways furnishes an opportunity for their use between points where road conditions formerly precluded regular operation by any kind of motor vehicle. Between localities where an infrequent headway is all that the traffic requires, and where the business is not sufficient to justify permanent track and overhead construction, a motor bus can fill a distinct need.

If autobusses are going to be required to operate a regular dependable service, as is now being operated in this country by the electric railways, over routes comparable in length with the street railways, they cannot operate for less money than the street railways; in fact, under equal conditions, they cannot render similar service at a profit at the same fare. Here again this situation points to the fact that the busses are a supplemental and auxiliary form of transportation to the electric car and not a transportation that can supplant the electric car.

The street railway companies need to view this problem in a sympathetic way and should recognize the fact that, if not properly and intelligently developed by the street railway companies themselves, the autobusses will be used by others in unfair and destructive competition in detriment to the service as a whole now rendered the public. We need to be careful not to let our conservatism stand in the way of encouraging, directing and controlling this new form of transportation, which can be developed to a great value to the industry as a supplement to electric railways, if handled in a farsighted manner.

Constructive Electric Railway Work

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THE accomplishments of the American Electric Railway Association have been of great magnitude during the past few years. The problems accompanying the great war may have been the underlying cause, forcing all members to realize the impotence of scattered effort and the necessity of utilizing the talent and full strength of their organization. The splendid manner in which the Association responded is now common knowledge. The records, of course, will not and could not do full justice to the patriotic and untiring efforts of the men who did this great work, especially the War Board Committees who were confronted with discouragement day after day. The work of this Board was followed by the Reconstruction Committee and the Committee on National Relations, as well as the Committee of One Hundred and others.

The great and lasting benefits of all this work to the electric railway industry and our country, as a whole, are immeasurable. The full benefit and force of the recommendations of the Federal Electric Railway Commission will be in proportion to the extent that its deliberations and advice are absorbed by the people generally. Measuring this part of the problem by the way the Association has performed on other matters, it may be depended upon that these recommendations will receive the full measure of effective publicity that they deserve.

The Convention at Atlantic City this month promises to be the greatest in the history of the Association. It will represent, as it were, the blossoming out of intensive constructive effort. It will be the forum for expression of the feelings of gratitude and satisfaction for Association work well done, as well as that of planning even greater Association accomplishments for the future.

A glance at the program outlining the subjects before the Convention for general discussion is ample evidence to show the thorough grasp the Association has on all problems confronting the industry. The Engineering and Statistical Bureau, now established at the Association headquarters, is a very marked achievement in the annals of Association practice. Its accomplishments up to date far exceed in value and scope that of any other similar Association activity in the country. In brief, the American Electric Railway Association is, in naval parlance, "stripped for action.".

The Best Plan for Operating Street Railways

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THE report of the Federal Electric Railways Commission has given a tremendous impulse to the consideration of the service-at-cost principle. The term is no longer a slogan; it can no longer be regarded as a theorists fad although, like all forward-looking movements, it will probably justify neither all of the fears of its opponents or all of the hopes of its proponents. It possesses no magic to make a 2.5 cent nickel worth twice as much in the purchase of transportation as any other commodity. This ought to be self-evident yet, less than a year ago, a well known authority on street railway operation pronounced service-at-cost a failure because it had increased fares in Boston at a time when almost every street railway operation in the country was attempting to extricate the industry from the trap of its own setting of the nickel-a-ride fallacy.

Is it then surprising that some of the public in some places felt that they had been burdened when a service-at-cost franchise failed to meet the rising costs of operation with a falling fare. The operators, too, have not always met the plan with full fairness and have been inclined to use it as an "Oh Lord, anything" but slyly trying to get its advantage without conceding the full measure of compensatory control by the community.

It is amusing to hear the demand from some quarters that regular restrictions be thrown aside and the industry allowed to resume its prewar normal method, in the face of the fact that the old system was so faulty that it required only the economic push of war conditions to bring about an almost complete collapse of the industry. Service-at-cost is going through its infantile baptism of fire. It does not want to be anybody's fairy godmother. It wants a square deal to show that it is based upon sound economic and governmental principles. Under the most favorable opportunities it cannot be a cut-to fit garment that will automatically produce standardized results in an industry which is as variable as the topography, habits and temperaments of the public it serves.

Those who do not approach the consideration of this question with a full conception of the public nature of a street railway enterprise are likely to fail in a complete understanding. Disregarding the finer distinctions of some recent court decisions, it may be assumed broadly that a municipal government is charged with certain basic obligations, one of which is to furnish the avenues and opportunities for convenient and economical transportation. If it does not elect to do this by direct operation, it must create an agency that will take over the responsibility under its direction. It must see that this agency puts itself in the place of the government and deals fairly with the members of the community and the government must deal fairly with its agent. This is the underlying philosophy of the service-at-cost plan. So much for the fundamentals. The practical application of these principles presents the problem for consideration.

Recent service-at-cost franchises have been enacted under conditions complicated by the state and municipal legal restrictions, traditions and questions of expediency and personal equations, so that ideal results could hardly be expected. Every franchise differs from every other franchise, and not the slightest effort has been made by anyone toward standardization.

For example, substantially every one who has thought upon the subject agrees that some incentive should be offered to the private company beyond the mere limited return upon the investment. Without this, there is little reason to expect the highest efficiency in operation or the keenest efforts to obtain labor and materials at the best prices, yet only three of the franchises in operation, and one of the many that failed, have any provision of this character. All of these differ. In Montreal, a bonus of 1/8 of one percent is given if the Company will keep within 102.5 percent of its operating allowance. In Cincinnati a division of the surplus is given to the Company as a reward for lower fares. In Dallas there is an allowed graduated increase from seven to nine percent in the return for the companies if fares are reduced from 22 tickets for $1.00 to 32 tickets for $1.00. Denver's proposed franchise allowed an addition of one-fourth of one percent for each reduction below 6.5 down to 5 cents, and one percent if fares remained under 5 cents.

A very interesting plan has been worked out by Mr. T. Fitzgerald, a consulting engineer with wide practical experience, which has not received the attention to which its importance entitles it. It provides an incentive to furnish good service and is predicated upon the sound theory that the property in street car operation is just as in any other business. It depends upon the character of service offered. Increased business will follow properly increased service. Therefore, his plan of reward is based upon increased traffic. It becomes an incentive to increased earnings rather than impairment of service.

Methods of control are equally varying. One city centers the control, another scatters it over various departments, even sharing with the state, one gives direct control, another indirect or implied control. In some places there is a single headed department, in another a board. One city includes franchise taxes, paving charges, bridge rentals, etc., as part of the cost of service, another eliminates all of these charges. The difficulty in making comparisons under such circumstances is obvious.

What is needed now is standardization based upon experience and education that will be broad enough to reach all of the interests concerned. No one will dispute the statement of the Federal Commission that the vital requirement of the industry now is the rehabilitation of its credit. The service-at-cost as yet has not done this. There are two reasons: One is that the public utility securities have passed from the speculative to the conservative field, but the investing mind of the public has not adjusted itself to the situation; the other is that the banker has not indicated "Sold" on the service-at-cost idea and consequently has not taken up his legitimate share in the working out of the problems. The process of getting this over to him and to his customers must be taken up nationally and not piece meal and it is somebody's job to do it

It is time to quit exchanging hard luck stories and to get down to brass tacks. Perhaps the service-at-cost idea is not the solution but, aside from municipal ownership, it is the only thing that has been offered. Therefore, isn't it common sense to dig into it and find out its strong and weak points and work out a standard franchise, elastic enough to fit the average community and get the American Bankers Association, national and local chambers of commerce, public officials and the public generally all over the country to understand it and to bring as much of it as possible into practical operation or, in the processes of this procedure, to develop the ideal thing which is to take its place and rehabilitate this essential industry. A sufficient number of cities are now operating under this plan to afford valuable experience as to the strong and weak points of the present franchises.

Increased Railroad Rates as an Accelerator of Electrification

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MANY GENERATIONS of railroad officials have been continually pestered by a multitude of people to try new things, ranging all the way from the man with new window hardware to the expert who says the roads could save $1 000 000 a day if they were properly run. While perhaps no class of men are more keenly alive to the possibilities of progress, charged as they are with the duty of conducting safe and reliable transportation, and realizing as they do the possible disaster which may follow ill advised experiments, they are proverbially disposed to let some one else be the first to try out a new method. This attitude of mind readily explains the railroad executives' original attitude towards electrification. This attitude was confirmed by the perhaps too enthusiastic and optimistic claims originally advanced by the advocates of electrification, which claims were further discounted by the contradictory statements made about the different systems.

As time passed and first one and then another of the strong progressive railroads ventured upon electrification projects and results began to speak for themselves, the mental attitude of railway executives, as a class, underwent a natural change. They were now able to obtain first hand information from other railroad men in whom they had the utmost confidence. The ultimate result is that the original feeling of hesitation and mistrust has largely been eliminated and has been replaced by one of confidence, in many cases, even of wonder at the transportation miracles which electrification can perform.

While what might be called this educational process was in progress something else was happening. Hampered and throttled by a poorly designed system of regulation, although in the midst of a period of unexampled industrial prosperity for all unregulated activities, the railroads were being slowly strangled to death. Their resulting impaired credit, not only increased the hesitation and decreased the ability of their managers to make the heavy additional investments required for electrification, but also turned all thought and effort to other immediate and more pressing problems. The recent Federal Railroad legislation seems to have been a sincere attempt on the part of our legislators to rehabilitate the financial status of the transportation companies, and the action of the Interstate Commerce Commission in granting the full amount of the rate increases asked for by the railroads, indicates clearly that the Commission realizes the trend of public opinion and does not propose to be held responsible for the failure of recent legislation should the results not be all that has been hoped for. There are indications that the railroad men themselves not only have a feeling of keen satisfaction at the relief now afforded them but also that they realize that, having been given all they asked for in the way of rate increases, it is up to them to make good. Now that the railroads are again in the hands of the men in whom they have had confidence in the past, it is reasonable to suppose that the financiers, who must be relied upon to provide new railroad capital, will use their best efforts towards rehabilitating railroad credit. Assuming these efforts to be successful, it is natural to expect that many electrification projects already in various stages of consideration will soon begin to be authorized and that increased activity in this branch of the electrical industry will result. Rome was not built in a day and the rehabilitation of so tremendous and so sensitive a thing as railroad credit cannot be accomplished over night. We must not be disappointed, therefore, if this predicted activity shall be slow in developing. That it should be slow is perhaps fortunate because the efforts of industry in general to catch up with the demand for all sorts of electrical equipment to supply the shortage brought about by the war, has overtaxed the country's manufacturing facilities, and it will take some time for these industries to return to a normal basis. As they do so, if the demand for electrical products for the railroads shall gradually grow, a very happy condition for all concerned will be created. It is a time for patience and conservatism on the part of all concerned but we may all confidently face the future with well-grounded hope and abundant courage.

Selection of Motors for Service Conditions

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THE selection of railway motors to meet service conditions is a most important preliminary to securing reliable, adequate and economical transportation. It was early recognized that the great variety of conditions to be met in different localities, such as profile, alignment, climate, etc., together with the variations in speed, stops and live load occasioned by the seasonal, daily and hourly requirements, made the correct application of motors a real engineering problem of no mean scope. The method proposed and described by Mr. N. W. Storer in his paper* in the STREET RAILWAY JOURNAL for Jan. 5, 1901, p. 67, is based on meeting the fundamental conditions with motors having series characteristics, and is recognized as the standard way for choosing motors to meet the requirements of railway service composed of a number of cycles differing from each other in numerous elements.

Most of the early railway motors (following the pioneer types) were limited in commutating ability by the state of the art at that time and utilized materials rather liberally. The result was that a motor, selected to develop ample starting torque within its zone of passable commutation and to perform the average service without exceeding the safe temperature, possessed the heat-absorbing capacity and ruggedness to withstand, without serious distress, the overloads encountered in emergencies. Various features of progress in electrical design, such as commutating poles, resulted in the development of motors having their commutating ability greatly increased as compared to their ratings. This made it possible to work motors nearer their continuous ratings under average conditions, in those cases where previously the commutation had been the real limit in application. However, this was accompanied by higher average operating temperature and, therefore, less capacity to meet emergencies, necessitating more care in selection.

Greater knowledge of the mechanical properties of materials, the demand for weight reduction, and refinements of design, such as self-ventilation, further modified motors to give us the modern types. All of these improvements tended to decrease the amount of material required for a given rating so that a 40 horsepower motor today has very much less ability to absorb the heat generated by short-time overloads and emergencies than had a 40 horse-power motor of ten or fifteen years ago. This is partly offset by the lower average operating temperatures of ventilated motors, but the net result is that careful selection is more important than ever before. In fact, the ability of railway motors to withstand the abuse to which emergencies subject them has been seriously impaired in the standard modern designs. It is yet physically possible for such motors to meet emergencies, such as running to the barn with half the motors in the equipment cut out, pushing in a dead car, and bucking snow. However, the penalty in damaged equipment is too great to be economical, especially under snow conditions. The situation is merely one more instance for applying the old adage that "You can't eat your cake and have it." In other words, it is unreasonable to expect a motor, refined to the limit of light weight, to perform without failure service whose very nature requires an excess of material and capacity.

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This "red flag" is pertinent at this time, as the season of severe weather conditions approaches. It is suggested that it be seriously considered to the end that suitable precautions be taken and adequate equipment be provided to protect electric railway service effectively against the repetition of such epidemics of breakdowns as were experienced in some localities during the winters of 1917-1918 and 1919-1920.

Service versus Fares

How Electric Railway Companies are Making Use of Operating Economies and Advancement in the Art to Offset Rising Costs

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THE skillful and efficient production of street car rides has always been, even as now, the problem facing electric railway managers. From the earliest beginnings of street railway transportation, when franchises were considered an asset rather than a liability, down to the present time, it has been the greatest hope of the industry that advancements in the art would result in exceptional profits. The changes from animal to electric traction gave a tremendous stimulus to these expectations. It is now a matter of history how the advantages of electrification, such as larger cars, increased speed and the apparent substitution of a permanent investment in power for a former transient one in the case of the horse, were offset by the necessity for an increased investment in rails, cars, overhead line construction, power and other electrical equipment, and in fact the substitution of a completely new and expanded facility for one that was obsolete and inadequate.

During the intervening years tremendous strides were made in the economic production of all elements entering into the cost of transportation. The steam turbine replaced the reciprocating engine, thus affecting a saving of one-half or two-thirds in the cost of power. For the comfort and safety of patrons, as well as for the increase in the life of equipment, substantial and well-built rolling stock was substituted for the original horse car. With this came necessarily a heavier track construction with the rolled-steel girder rail replacing the former strap iron track work. Electric heaters replaced the straw pile, and the Mazda lamp was substituted for coal oil.

The development of the electric motor and its suitable control equipment, is a part of the history of electric railway operation. From the open construction, double-reduction motor first installed, when flash overs and insulation break downs were of daily occurrence, to the present commutating-pole, enclosed motor of rugged construction and comparative freedom from breakdown, is included a period of hundreds of designs, examples of which may be found on most electric railway properties. Second only to the introduction of the electric motor has been the adoption of improved air brake equipment, with various auxiliary appliances for both service and emergency operation, and for the greater ease in application on the part of the motorman.

Today, a thousand inventions and appliances, due to the combined efforts and inventive genius of manufacturers and operators, cater to the comfort, convenience and safety of passengers. Electric signal devices, electrical and mechanical interlocking appliances for the control, and simplified operation of doors and steps have made the handling of passengers safe and efficient. Developments in car body construction, such as the arrangement of seats, aisle spaces, platform details, step heights, and improved means of ventilation, have made riding on surface railways an attraction rather than a necessary evil. Passengers may read while riding and if necessary, even write, both now difficult or impossible in a bus. The modern electric car is in fact a structure designed as carefully and as proportionately correct as a steel bridge, and with as many of the facilities for comfort and convenience as can be furnished readily, without sacrificing its principal function as a carrier of passengers.

The standardization of the facilities and equipment used in electric railway operation has been a goal long desired by electric railway operators. Fortunately or unfortunately, depending upon the viewpoint, progress has been so rapid that this has been practically impossible. Today, the standardized safety car is replacing the older two-man cars of heavier and larger construction, admirable and well fitted to the purpose though the latter were. Electrically and pneumatically-operated devices and the virtual automatic functioning of all its equipment are the features of this latest development in car construction. Along with the safety car, in the utilization of labor saving devices, has come the automatic substation, whereby the conversion and distribution of electric energy, now generated most efficiently in high powered turbine stations, can be secured without the aid of substation attendants as heretofore. In track construction, almost equally radical developments have been made. The bane of the track man's existence and the most difficult problem in track construction, namely the rail joint, may now be eliminated. Electric welding provides a continuous road of smoothest steel, free from the knocks and jolts formerly connected with the inevitable worn out joints. Almost equally important is the permanence and solidity of the concrete track roadbed now largely used in paved city streets.

Aside from these advancements in the physical art, considerations of efficiency and methods of economic operation have been the subject of much study in the field of actual operation from the traffic standpoint. Primarily, the function of a city transportation system is to provide convenient and adequate communication along the arteries of traffic flow. Its efficiency is measured by its success in fitting units of service to the traffic. The determination of the origin, destination, direction, intensity and time of the traffic stream, and the fixing of car schedules for the greatest good of the greatest number, is the real problem in transportation engineering. In many cases this involves the elimination or abandonment of certain service which is operated in duplicate; the installation of turn-back service at the outer ends of routes; the establishment of cross town routes to reduce the length of haul; the operation of shuttle cars on the stub end lines, and in general the scientific routing of all cars to meet the traffic demand, based on surveys showing the actual trend of traffic.

Many improved operating methods of more or less recent development have come to improve further the efficiency of operation. It is recognized that the most important factor in transportation is speed, both from the standpoint of the passenger and the company. To this end, the skip stop was instituted, although primarily established as a power saving device. It is notable, however, that this, as well as many other methods for speeding up cars, is based on the elimination of standstill and the slower running times, with a view of bringing up the average speed, rather than on any increase in the maximum running speed. Among such schemes are the use of safety zones and loading platforms to facilitate boarding and alighting; the multiple berthing of cars at congested street intersections; the improvements in traffic regulations, whereby vehicles are kept off the tracks and cars given the right of way; the elimination of parking of automobiles in certain districts, thus increasing the effective width of street and increasing the number of lines of vehicles for a given street; the rerouting of cars and vehicles to reduce delays; and the utilization of the one way traffic principle on certain streets. In fact, scientific studies are now made of the traffic capacity of congested streets and important intersections, and changes in routing and traffic regulations are made to prevent excess loading.

With all of these facts in the possession of the electric railway management, the co-operation of the public must be secured by means of suitable publicity. The electric railway's problem is largely now the public's problem. Never before has the man on the street had an opportunity of becoming so conversant with the details of street railway service as at present. The problems of power supply, the increase in cost of labor and material, the questions of car service, are all matters of public information. The financial statistics of electric railway companies are no longer a mystery nor a secret. Good service is understood to be good cars, good roadbed, better speed, frequency, comfort, safety, regularity and the courtesy of employes.

Probably the most significant change that has taken place in the transportation industry is the loss of its supposed character as a monopoly. It is now in competion not only with the automobile, the motor bus and the jitney, but also with the telephone and telegraph. Electric railways now realize as never before that they must sell their transportation just as the merchant sells his goods.

Purchased Power for Traction

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THE time was when mother made the small boys' clothes. She did the tailoring, not because she loved the work, but for the simple reason that ready-made clothes were not available. Likewise, the time still is when many electric .roads run power plants, and they are running them, not for the fun of it, but for the good reason that "purchased power" is not to be had. The interurban manager cherishes no illusions regarding the power plant. He has seen the romance of pioneer days flit out the window as efficiency walked in the office door. He knows that his plant of ten or twenty years ago, with all its betterments, cannot produce power as cheaply as he could buy it, if he were in the zone of a superpower plant of today. He realizes that the production of power and the production of transportation are two distinct fields of public service, each a specialty of an exacting nature, and that interurbans are no longer a popular investment.

Selling transportation at a reasonable profit has long since become a feat of rare occurrance, and never so rare as now. How to keep the outgo from eclipsing the income is the problem. The answer, of course, is to decrease the former and increase the income. A reasonable increase in rates would be a great boon to the interurban, but before the Commission will allow an increase, the road must show that it is doing its best with the facilities available, and still is not getting a fair return. Scanning the operating expenses in search of further economies discloses no promising prospects. Minimizing "Maintenance of Way and Structures," and "Maintenance of Equipment" is only compounding the expense. The biggest group of all the operating expenses, "Conducting Transportation", is the one over which the management has least control. The remaining groups, except "Power", are small and if shrinkage remains in any group, it is in "Power".

Power ranges as high as twenty-five percent of the operating expenses. A reduction in kw-hr. consumption or kw-hr. price might be possible. The obvious ways of reducing consumption are,—better handling of cars, use of more efficient equipment, use of lighter cars with modern equipment, use of automatic substations (they run only when they work) and curtailing of wasted kw-hr., though this is a difficult achievement when the current comes from the family plant. It is equally obvious that these betterments might require financing and supervision that are prohibitive.

A reduction in the price per kw-hr. is possible, if the plant economy can be bettered, but betterments soon reach the point of diminishing returns when applied to models of a decade ago. The alternative is purchased power, provided there is a modern plant within tapping distance. Purchased power at an attractive price, a cut in the substation payroll effected by automatic substations and a more productive use of power, due to closer scrutiny of application that obtains when current comes through a taximeter instead of from the Company's generous power plant, would achieve a reduction in power costs. However, all possible reductions in operating expenses that the analysis may show are not sufficient to meet the case. A reasonable rate also must obtain.

In the meantime, the power industry is expanding at a rapid rate and plants are being interconnected. The interurban cannot migrate to the power plant, but power systems are stretching out and steadily increasing contact with the interurbans. The interconnection of power plants is not only a possible source of relief for many small roads, but for some of the big ones as well. Many of the latter are consolidations of one time independent lines and the merger has led to a consolidated power plant. There are numerous traction centers from which several such interurban systems radiate. The inter-connection of these consolidated plants likewise offers possibilities for economies and, as obsolescence claims even these big plants, would logically, lead to a superplant for all the roads in the territory.

The steam road projecting an electrification should be able to buy power as it buys coal, delivered to the track. This would narrow down the road's electrical investment to practically the trolley construction and the locomotives. However, it is indispensable that the power price be reasonable and that the supply be reliable. The big power company is a professional in the matter of power production and has a diversity of load that gives the reserve equipment plenty to do. The power company accordingly can take on the railroad load with less increase in operating expense and investment than the railroad would incur in producing its own power. The investment charge has to be paid in either case. Buying power, the road pays the investment charge on the power plant, the high tension system and the substations as an operating expense, in the price for current, in the same way that it pays the investment charge on the coal mine and plant in the price of coal. The fact that the investment charge and operating expense are relatively less for the power company than for the railroad means that the railroad should be able to buy power cheaper than it can produce it.

Independent of the matter of price, the matter of reliability of supply is the one of first importance to the railroad. But it is equally important to the power company, with not only the railroad dependent upon it, but factories and general illumination as well. The power company must and does take the necessary precautions to protect its customers and is probably better safeguarded against shutdowns than the railroad is against washouts.

That the power company can meet the exacting demands of railroad service is demonstrated daily. The Pennsylvania Railroad buys power for its Philadelphia electrification. The Michigan Central buys power for the Detroit River Tunnel locomotives. The Grand Trunk Railway now buys power for its St. Clair Tunnel electrification. The Piedmont Traction buys power. The Milwaukee buys power for all its 660 miles of electrified route. The Spokane and Inland Empire buys part of its power. So do many other roads in the west, as well as in other parts of the country. Power production has become a huge business. It is a basic industry like transportation, and supplying energy for transportation is one of the big roles it is destined to play.

A proper form of contract between the power company and the railroad is being evolved. It is fair to both. It is self-explanatory and safeguards both investments, and is capable of revision to meet changing conditions. We are not talking indiscriminate purchase of power for electric roads. It is not a universal solvent. Each road requires a special study of its power problem. The subject, however, is timely and we are quite sure that many an interurban manager with a power plant on his hands and losing sleep, wrestling with ways and means to increase his "Net", is giving serious attention to the matter of purchased power. It merits discussion.

Severe Winter Operating Conditions

Practical Methods for Minimizing Possible Troubles

JOHN S. DEAN
Railway Motor Dept.,
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THE PROBLEM of operating street cars during the winter season, especially in the sections of our country frequented by heavy snow storms, is one that vitally interests all street railway men from the president down through the organization and including the men in the shops and car barns. To the officials a snow storm means financial loss, due to reduced earnings and increased operating expenses, and in addition creates an antagonistic public sentiment very detrimental to the interests of the company. To the average employe of the company it means longer hours of labor, followed by physical discomforts, and in spite of their increased earnings and larger pay envelopes, they become inefficient and discouraged, with a resultant breaking down in morale.

Depending upon the geographical location of the operating company, interest in this subject varies. Operators in the extreme south, need give this subject but a passing thought, while railway companies facing conditions such as shown in Fig. 1, are vitally interested in this subject. It is generally conceded that in this country a line passing through Washington, Cincinnati and St. Louis, approximately the 37th degree of latitude, represents an intermediate point between the two extreme conditions referred to above.

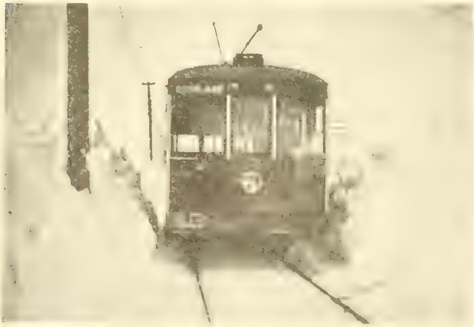

FIG. 1—SNOW CONDITIONS WHICH CAN ONLY BE MET WITH SPECIAL [illegible]

[illegible] EQUIPMENT [illegible]

Careful analysis of the operating conditions and equipment failures on a number of street railway properties during the winter season, combined with an expression of opinion from a number of men closely allied with the railway industry, shows the following primary causes as being largely responsible for equipment failures:—

a—Heavy snow storms block the track, subjecting the [illegible]

b—Inadequate and inefficient snow fighting equipment is unable to keep tracks clear, thus compelling the use of passenger cars to do a large share of this work.

c—Snow and ice is packed between the rails by automobiles and heavy trucks. Under these conditions cars are lifted off the rails by motors riding on the ice, thereby spinning the wheels and roasting out the windings. Motors are overloaded and sometimes burned out as the result of gear cases rubbing open on the ice and allowing the snow and ice to pack in the case, jamming the gears.

d—When a thaw comes the snow melts rapidly, and with sewers choked, the tracks are covered with water and slush through which cars must operate, resulting in wet motors, due to wheel splash and to depressed sections of the track pocketing the water.

e—Cars are used to pull in cripples, overloading the motors.

f—Due in most cases to forced neglect of maintenance, the equipments are in a general rundown condition, and are physically unfit to meet the emergencies caused by overloads.

g—All available equipments are overworked, as a result of the many crippled cars in the barn and the increased travel, due to poor weather conditions.

h—An increased number of mechanical failures is due to the extreme low temperature, frozen condition of the road bed, and to the action of the frost on the road bed and track.

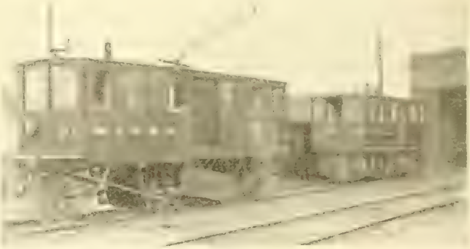

FIG. 2—TYPICAL SNOW SWEEPERS

i—Sweating of motors that are parked in zero weather all night, after being worked to the maximum temperature the previous day.

j—General demoralization of schedule, due to crippled cars and stranded automobile trucks tying up traffic.

k—Rough and careless handling of the equipment by the train men, who are forced to make up lost time due to unavoidable delays.

l—Extreme cold weather and uncomfortable condition of the pits and car barns, reducing the efficiency and the morale of the workmen, resulting in makeshift repairs and poor maintenance.

m—Poor shipping facilities, resulting in a scarcity of repair parts to maintain the equipment properly.

RELATION OF FAILURES TO TYPES AND MAKES OF MOTORS

The experience of the past few years, and especially the past winter in certain sections of the country, has demonstrated that in order to cope effectively with the heavy snow fall and severe winter weather conditions, adequate preparation must be made. An efficient snow fighting organization, with effective equipment, must be maintained to combat these unusual operating conditions properly. Evidence collected from 15 representative operating companies by an official of a large railway company in New England was segregated and tabulated, showing that armature failures due to severe winter conditions during the early part of the present year were on the average about equally divided between those of the two large motor manufacturers.

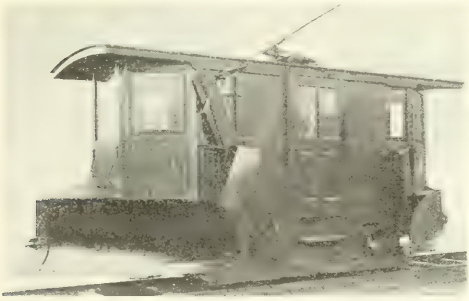

FIG. 3—SELF PROPELLED NOSE PLOW FOR SINGLE TRACK ROAD

It further showed that approximately the same percentage of failures occurred on both the commutating-pole and noncommutating-pole motors and with the non-ventilated as well as with the ventilated type of motors, which indicates that this epidemic of motor trouble during unusual weather conditions is no respecter of the manufacturer or the type of motor construction. It was definitely shown that certain properties operating under practically the same conditions had less trouble than others, which was only accounted for by their more thorough preparedness to meet these emergencies.

PROPOSED METHODS TO REDUCE FAILURES

Some of the lessons learned by this investigation and from data obtained through other sources of information bearing on this subject, which were gathered from a number of other railway companies operating in various parts of the country, have suggested the following points.

Organization—It is of vital importance to have an efficient and well organized body of trained men under the supervision of a competent master mechanic to take care of all repairs.

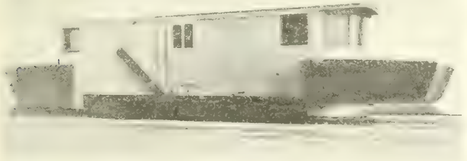

FIG. 4—SELF PROPELLED SHEAR PLOW FOR DOUBLE TRACK ROADS

Regular and Systematic Inspection—To keep all equipment tuned up to meet emergencies and to catch partial defects in equipment before they go too far and cripple the cars in service, regular and frequent inspections should be made at stated intervals of time or on a mileage basis, and at least once a year all equipment should be given a general overhauling.

Dipping and Baking—Completely wound armatures and field coils that have been thoroughly treated by dipping and baking, using a good grade of baking insulating varnish, have been found to withstand the water and moisture encountered during the winter season with less resultant trouble than untreated windings.

FIG. 5—THE PUSH TYPE OF SNOW PLOW

This treatment of windings has been highly recommended as a means of fortifying them against grounds and short-circuits. Reports submitted in the above investigation by two operating companies who did not dip and bake their armatures show that 58 and 43 percent of the total number of armatures in service had failed, while two other companies that give their armatures this treatment reported armature failures of only 20 and 14.5 percent, respectively.

Motor Leads and Car Wiring—All motor leads should be cleated to prevent rubbing and chafing, and thus reduce the number of grounded or broken leads. Broken leads may occur and cars be operated with only three motors in service for some time without detection, thus overloading the motors and roasting the insulation. A heavy coating of moisture proof asphaltum paint protects these leads against snow and water. All unprotected car wiring should be well cleated to prevent rubbing, and should be painted with a heavy asphaltum paint to keep out the snow and water.

Motor Covers—Suitable tight fitting solid commutator and hand hole covers should be placed on all non ventilated motors, to prevent snow and wheel wash from getting inside the frame and damaging the windings and the brush holders. Armature and axle bearing oil-well covers and all dust shields should be made

FIG. 6—[illegible]
STANDARD EQUIPMENT

tight fitting and should be securely fastened to keep water, dirt and snow from getting into the bearing. Motors of the ventilated type, that ordinarily operate with perforated covers, should be provided with solid covers wholly or in part for winter service. The application of solid covers to these motors should, to a large extent, be controlled by local conditions, such as the maximum operating temperature of the motors and the severity of the winter, as judged from the average yearly snow fall. In general, where the operating temperatures are as low as 55 to 60 degrees C. rise, solid covers should be applied during the winter months in localities subject to snow. If the operating temperatures are above 75 degrees C. rise, and the snow fall is light, the regular ventilated covers should be used all the year round. Where the snow fall is heavy, solid covers should be applied during the winter months, regardless of the temperatures.

Motor Drain Holes which are provided in the bottom of the motor frame castings quite often become clogged with dirt, snow or ice. During the regular inspection period these holes should be cleaned out and openings cleared.

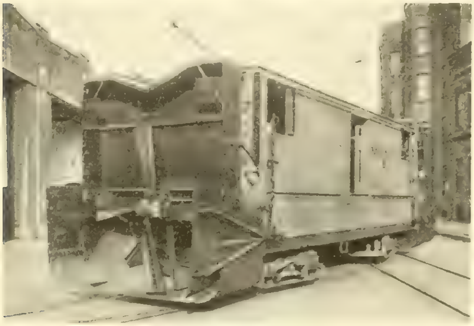

FIG. 7—THE ROTARY PLOW
The snow is sliced by the cutting blades at the front of the car and thrown out to one side by the fan just behind the cutting blades.

Gear Cases are subjected to bumps and severe strains, due to snow and ice between the rails, and for this reason they should be clamped securely to the supporting lugs, by keeping the clamping bolts drawn up tight and securely locked. The two halves should be carefully fitted together and all covers made tight to keep out the snow and water.

Axle Cap and Motor Frame Bolts It is very important that all bolts on the motors be kept tight and securely locked, to prevent parts from working loose, thus allowing water to enter into the motor frame and bearings. These bolts, which should be made of a special heat treated steel, should be carefully gone over and tightened at each regular inspection.

Bearings—By giving careful attention to the packing and oiling of bearings, using a clean, long-fibre wool waste and a good grade of winter car-oil, bearing trouble will be reduced to a minimum. A further great saving in maintenance and reduction in the number of motor failures can be obtained by a careful and regular gauging of the armature bearing wear, using a feeler gauge in the air-gap. Bearings that are worn approximately 1/16 inch should be replaced to prevent the armatures from getting down on the poles and damaging the windings.

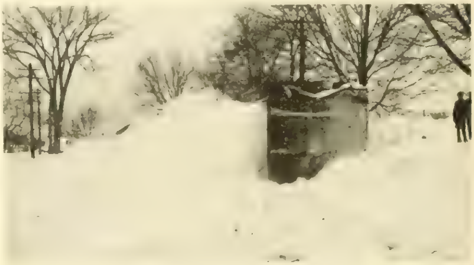

FIG. 8—ROTARY SNOW PLOW IN ACTION
On the Holyoke Street Railway lines.

Detail Apparatus—The windings and leads of all detail apparatus should be thoroughly painted with a good grade of asphaltum paint and should be provided with tight fitting covers. Suitable splash guards should be properly located to prevent, so far as possible, the snow and slush from lodging on resistance grids, motors, wiring, and other parts of the equipment.

Available Spare Parts—It is good practice to keep an ample supply of spare parts in stock to meet emergencies. This is especially important at the present time, owing to the long delivery date for spare parts forced upon the manufacturer by the condition of the labor and material market. It is also well to remember that the shipping facilities are not very reliable during the winter, and although the material may be available for shipment, any promise of delivery cannot be depended upon under existing conditions.

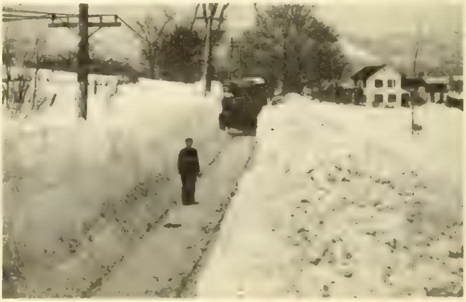

FIG. 9—CUT MADE BY ROTARY SNOW PLOW AT HOLYOKE, MASS.

Condition of Pit and Barn—A factor that is too often overlooked is the condition of the inspection pit and car barns during the winter season. In many cases the pits are poorly lighted, wet, dirty and littered with tools and broken repair parts. Many car barns are not provided with storm doors, and are poorly heated, resulting in cold, damp, uncomfortable conditions under which the men are compelled to do their work. These conditions have a tendency to reduce the efficiency of the workmen, who slight their work and congregate around a stove to thaw out and be comfortable.

SNOW FIGHTING AND EQUIPMENT

The organization of a city fire department is considered to be the last word in preparedness for combating fires. It has been suggested that the snow fighting forces of a street railway company be organized along similar lines. Experienced and reliable crews should be assigned to the different types of snow fighting equipment operating from the various car barns, so that on a comparatively short notice this equipment can be placed in service to clear the tracks.

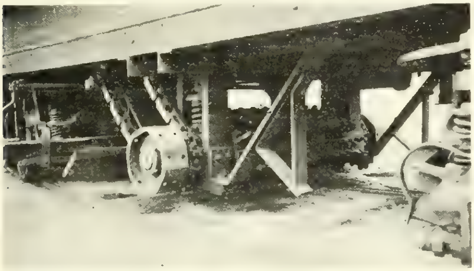

FIG. 10—ROTARY ICE CUTTER
Used by the International Railway Co., Buffalo, N. Y.

A Definite Program—Railway operators can learn much from the army strategists, who before any important battle, make a careful study of the minutest details of the strength and the distribution of the enemies' forces, to determine their vulnerable points. With this information and with definite knowledge of their own strength, an attack is planned and executed with clock like precision. In preparing to fight snow, the operating companies should make a careful study of the situation and map out a definite program which should take into consideration the following points:—

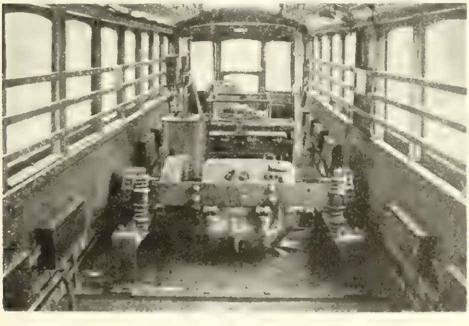

FIG. 11—METHOD OF DRIVING THE ICE CUTTER

a—Available snow fighting equipment.
b—Condition of equipment.
c—Spare equipment and parts.
d—A study of weather conditions.
e—Nature and severity of snow fall.
f—Assignment of the crews.
g—Routes of sweepers and plows.
h—Time of starting.
i—Emergency and relay crews.
j—Sufficient power supply—consider the use of portable substations.
k—Re-arrangement of schedules.

Equipment—Each individual operating company should determine the requirements for snow fighting apparatus based upon past experience. Railway companies with inadequate equipment are compelled to use passenger cars to keep their right-of-way open. Cars that are used in bucking snow may do this work without showing any immediate apparent injury to the motors, but it should be definitely understood that the excessive overheating of the motors by this overloading weakens the insulation of the winding and shortens the life of the equipment. This is especially true in the case of cars equipped with the light weight ventilated type of motor, which has a lower short-time overload rating.

The problem of keeping electric railway tracks clear of snow and ice during the winter season has been the means of developing a variety of ingenious devices, some of which have become standard pieces of apparatus and are used quite extensively by all of the railroads. One great fault in connection with this class of apparatus, and which is common with too many operators, is the use of old and obsolete electrical equipment which is nearly ready for the scrap pile, resulting in snow fighting machines that are not always reliable. Various types of apparatus used to clear the tracks of snow and ice, the details of which are well known to all railway operators, will be touched upon only in a general way.

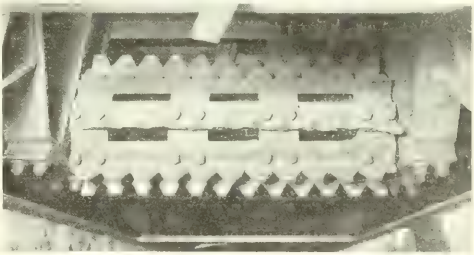

FIG. 12—DETAIL VIEW OF ICE CUTTER

A Snow Sweeper consist of either a four wheel or eight wheel self-propelled car, with a motor driven broom, rotating at an angle on the forward end of the car, which brushes the snow from the tracks, as shown in Fig. 2. This kind of apparatus is best adapted for use in light snows and for city work in general.

A Snow Plow consist primarily of a car with either four or eight wheels, self-propelled or pushed, having a metal or wooden shaped nose on the front end, which forces the snow from the track. This kind of apparatus is best suited for deep snows and for suburban and interurban lines. The various types of snow plows are:—

The Nose Plow, Fig. 3, with the tip or point of the plow coinciding with the center of the track, is self propelled and forces the snow on both sides of the right of way. This type is best suited to clear the snow from single tracks.
The Shear Plow, Fig. 4, with the tip or point of the plow offset from the center of the rails, is self-propelled and forces the snow to one side of the right of way. This type of plow is most commonly used to clear the snow from double tracks.
The Push Plow, Fig. 5, consists of a specially built car having the plow integral with the body of the car, which must be pushed by an external source of power.
The Pilot Plow, Fig. 6, consists of a sheet metal plow adapted to the front end of any standard type of self-propelled passenger, freight or express car.
The Rotary Plow, Fig. 7, consists of a self-propelled or an externally driven car, with a motor driven fan mounted at the front end, which throws the snow a considerable distance from the road bed. This type of plow is best suited for use in high drifts and deep snow.

Special Apparatus—Other detail apparatus used in fighting ice and snow is as follows:—

Snow Scrapers are fastened to the cars directly in front of the wheels to clear away the snow.

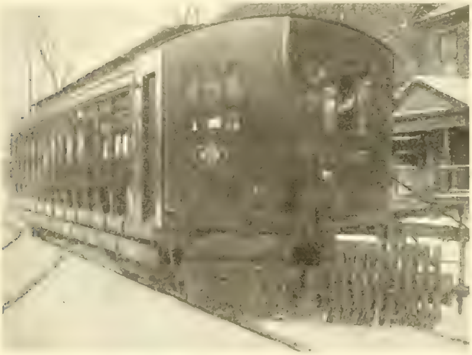

FIG. 13—SNOW SWEEPER MOUNTED IN FRONT OF STANDARD SUMMER CAR

Small Brooms or brushes are placed directly in front of wheels to brush away the snow.
Trolley Sleet Cutters are attached to the trolley to clear the sleet from the trolley wire.
Third Rail Sleet Cutters consist of wire brushes attached to the car in front of the third rail shoe, to clean the third rail. A chemical solution of calcium chloride is sometimes squirted on the rail to cut the sleet.
Switches—Salt is applied at spring switches to keep them operative. In cases of a heavy snow fall, shovels and brooms must be resorted to in order to keep these switches clear.
Snow Fences—The placing of wooden fences along the right of way at points subjected to drifts will prevent the snow from piling up over the road bed.

Ice Cutters—Since the advent of the low-floor car, operating on 24 inch wheels, snow and ice packed between the rails has caused considerable damage to the equipment under the car, on account of its small clearance to the road bed. A very effective device for cutting this ice, shown in Figs. 10, 11 and 12, consists primarily of a revolving cutter driven at 300 r.p.m. through a double chain drive, connected to a 50 hp motor. The cutter consists of a number of 1 in. by 5 in. by 5 ft. long standard angles with teeth cut in by an oxy-acetylene torch. These angles can readily be removed by taking out eight bolts. This cutter, which is spring supported, can be raised or lowered through a range of four inches to adjust itself to the thickness of the ice. This machine is run over the tracks and cuts the ice from between the rails. It is followed by a sweeper that clears the chopped ice from the tracks. This apparatus has proven so successful during the past year that two more similar machines are being built.*

A similar device has been built by another company, but so far it has not been given a thorough try out in service. In general it is similar to the machine described above, except that the cutters consist of a number of old gears, with alternate teeth cut away.

APPARATUS MODIFIED FOR SNOW FIGHTING

One large operating company, whose present equipment consists of 42 plows and 12 sweepers, is planning to add to their equipment for the coming winter. They have arranged to utilize 36 double-truck freight cars, having discontinued their freight service, and have placed orders for the necessary material to change these over into 17 sweepers and 19 snow plows. The work of reconstructing these cars is being done at the railway company's shops.

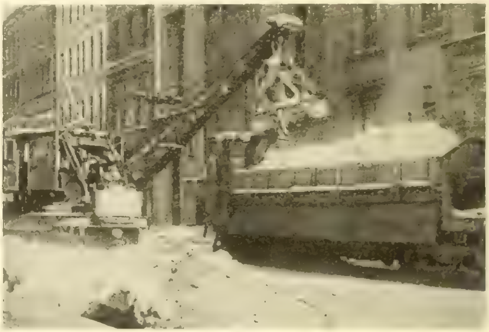

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FIG. 14—ELECTRICALLY OPERATED CRANE OF THE BOSTON ELEVATED RAILROAD

Removing snow from Frederal Street, Boston. Photo by courtesy of Industrial Works, Bay City, Mich.

An interurban company in the middle west have fitted a number of flat maintenance of way cars with a special pilot plow. These cars are heavily loaded and utilized as push plows during the winter season, with very satisfactory results. This changeover can be made at a comparatively small expenditure of time and money.

Fig. 13 shows a summer car that has been changed over to a snow sweeper for the winter service. This scheme was developed by Mr. J. W. Hulme, who states** that the initial cost of installing this sweeper equipment was $900, and the conversion at the end of the season can be made for approximately $30.

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*Further detail information regarding this machine can be obtained from Mr. J. W. Hulme, Supt. of Motive Power of the International Railway Company, Buffalo, N. Y., through whose courtesy this description and the photographs were made available.

**In the *Electric Railway Journal* for Jan. 18, 1918.

REMOVING SNOW FROM STREETS

In congested downtown districts of some cities it is necessary to remove the snow from the streets entirely. This work is usually done by shoveling the snow into wagons or cars, which must be hauled away and unloaded. In some cities, the sewers have been utilized to carry away the snow, by shoveling it into convenient man-holes. One novel and efficient scheme was the use in Boston during the past winter, of an electrically operated crane, fitted with a grab bucket for cleaning the streets of snow, as shown in Fig. 14.

REARRANGING SCHEDULES

Every railway company operating in the snow belt has experienced some demoralization of schedules, due to the unusual operating conditions encountered during the winter season. It has been recommended that in order to meet these unusual conditions a special snow schedule should be planned, which will give the motors a sufficient lay over at terminals, during snow storms, to cool off before making the return trip.

SYSTEMATIC PUBLICITY

A very important consideration, which is too often overlooked in connection with the operation of a street railway, especially during the severe winter season, is the need of keeping the good will of the traveling public. During these months there are a number of existing conditions beyond the control of the railway company, such as extremely severe weather; surface drainage, with resultant flooding of streets and tracks; congested street traffic; stranded automobiles and trucks; abnormal labor conditions; and shortage of coal. These factors tend to disorganize the transportation department and cripple the regular operation of the cars, thus arousing the indignation of the public, who are to a large extent ill-advised or ignorant of the facts. By the expenditure of a little printers ink in the form of posters, publications, or advertisements in the daily newspapers, the truth regarding these conditions can be brought forcibly to the attention of the people. In most cases this will result in securing their co-operation rather than their condemnation.

The Bus, the Trackless Trolley or the Trolley Car for Light Traction—Which?

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Westinghouse Electric & Mfg. Company

SO MUCH has been written relative to the above forms of transportation, their advantages and disadvantages, that many of us are perhaps inclined to beg for pity when someone starts in to hold forth again upon the same subject. We have been bombarded on the one side with articles setting forth that the gasoline bus was going to put the traction lines out of business, and on the other hand by articles stating with equal conviction that the bus never could hope to compete with the car on rails. The trackless trolley has also come in for its share of criticism pro and con so that, between the varying opinions expressed on the three forms of conveyances, the average reader finds his head in somewhat of a whirl and the question of deciding which has the most merit rather a difficult one.

The writer's object is to try to clear away a little of this fog by looking at the whole matter from the standpoint of the general fundamentals which must be considered and, it is believed, this will give a much clearer picture of the whole situation.

In the first place, the terms bus, trolley car, and trackless trolley are really names which have become attached, through association, with various traction vehicles used for carrying human beings without there really being any clear cut distinction. For instance, if we equip a vehicle of the type we are used to calling a bus, with wheels suitable to run on rails (as has been done) does it cease to be a bus? If we take a traction car off the rails and equip it with suitable wheels, does the change make it a bus? Is a bus a bus because of its form of construction, or because it runs on a particular form of road? Is a car a car because it runs on rails or because of the way it is built? If we follow this line of thought very far, we will soon arrive at the stage of mind where, like Alice in Wonderland, we won't know whether "cats eat bats" or bats eat cats".

Let us start, therefore, by trying to eliminate from our minds the terms bus, trolley car and trackless trolley, and think of the problem as one of providing a conveyance for the transportation of human beings in a quick, comfortable and economical manner. The fundamental points which naturally come up for consideration are—how many passengers should this conveyance carry? What should be its construction and weight? What power shall we use to propel it; and on what shall it run? Briefly stated, therefore, capacity, weight, roadway and propelling power are the big four which enter into this problem.

The first point, the proper capacity for our vehicle, could be easily settled if it were always to operate under a fixed and evenly distributed load condition, as it would then merely be a matter of deciding upon the frequency of service which we wished to maintain, and dividing the number of passengers to be carried per day by the total number of vehicles operating over the route during that period. Unfortunately, actual service does not present this ideal condition, as the load to be carried usually varies widely at different times of the day, and on different parts of the line, from day to day and with the season of the year.

We can meet the varying conditions, either by providing a vehicle big enough to meet the maximum load requirements and maintaining a uniform schedule all day; or we can provide a smaller vehicle, which will be just sufficient for the average load conditions, and run an increased number of these vehicles during the rush hours.

If we adopt the big vehicle solution of the problem, we will be hauling around for the major part of the day a heavy vehicle with a few passengers, but on the other hand during the rush hours, we will be operating at maximum efficiency, as the platform labor and weight per passenger will be a minimum.

If the small vehicle idea is carried out, that is, using one just big enough to accommodate the average load and increasing the number of vehicles as required, the platform labor and weight per passenger will be practically uniform all day, and during the hours of light load the cost of operation per passenger will be less than with the big cars, but on the other hand during the rush hours, the cost per passenger will be more than with the big cars, as a greater dead weight and increased platform labor are required per passenger.

Furthermore, it must be remembered that if we have enough of the light vehicles to take care of the rush hour conditions, for a considerable part of the day we will have a number of vehicles idle, which will to some extent offset the gain in efficiency during the average load conditions.

It will be realized from a consideration of the above facts that to determine the capacity of vehicle most economical for a given service, it is necessary to give most careful study to the traffic conditions in each case. This study must, of course, be made no matter what method of propulsion is employed, or what construction of roadbed is used.

The next point, the question of weight of the vehicle, will depend partly upon the capacity for which it is built and partly on the type of construction and materials employed. In general, in the past, vehicles which run on public highways have been built lighter than those which run on a steel roadbed (i.e. a railroad). This has been due largely to the fact that these vehicles are a development from the horse-drawn type, where the power available was very limited and weight a vital element. Of late years, the weight of the vehicle running on the steel road has been reduced until it approaches more nearly to that of the vehicle which runs on the highway, but has by no means reached the limit.

The builders of vehicles operating on highways have taken advantage of the use of high grade materials and have not, in general, found it necessary to provide many of the refinements of equipment which the public has been educated to consider as necessities in the vehicle which runs on rails, and have thus been able to produce a very light type of vehicle. It is important to note that there is no inherent reason why the vehicle on rails should weigh any more than the one on the highway for the same service and capacity of vehicle.

The third point, the construction and material of the roadbed upon which the vehicle will operate is of prime importance. "A railroad is only a road of steel" as Lord Ashfield remarked in a recent article, and it is a help in considering the whole problem broadly to keep this in mind. If the road is only a country one of dirt, likely to be at times full of holes, then springs must be arranged to carry the loads safely and with reasonable comfort over these conditions and, in general, it is found advisable to use pneumatic or cushion tires. As the conditions of roadbed become better, as in the case of cement, asphalt, etc. we reach a point where it becomes permissible to use solid rubber tires.

If we go a little further and build the road of steel, we attain such a degree of smoothness of surface and freedom from "chuck holes", etc. that we are able to use a metal wheel without a cushioned surface and can reduce considerably the action of the body springs.

The steel road has such mechanical strength and resistance to wear that we can use a very narrow strip. This, however, gives disadvantages as well as advantages. It would be manifestly impossible for an operator to steer along this narrow roadbed, so the wheels must have flanges; this, it is true, eliminates the necessity for steering and steering gear, but confines the vehicle to an absolutely beaten track. Among other attendant advantages obtained by the use of the "road of steel" are two very important ones. First, on account of the smoothness of surface which is obtained, the power required to move the vehicle on a level track is considerably less than that required with rubber tires on any other type of roadbed—in fact, it is not much more than half; and second if we decide to make use of electric power, the roadbed can be used for one side of the circuit.

The fourth point to consider is the question of the power to propel the vehicle. At the present stage of power development, this choice practically narrows down to the use of some form of internal combustion engine or the use of electric power. How shall we decide which to use?

Every horse-power-hour used for propelling the vehicle will cost approximately 8.5 cents if we use gasoline at the present price, and 1.3 cents if we use electric power; or over six times as much for the gasoline for the same power. But while this represents the figure at which electric power companies will supply power, we still must provide some means by which the current can be transmitted to the moving vehicle, as a storage battery is ordinarily too heavy and expensive to employ. This structure will cost money, which we would not have to spend if we used an internal combustion engine.

The simplest method which has so far been devised for this purpose, consists of one or two wires suspended over the route which the vehicle is to follow, and sliding or rolling contact devices on the vehicle to collect current from these wires. If the roadbed is a non-conductor, two wires will be necessary, and this construction will cost somewhere in the neighborhood of $7500 per mile.

It is evident that the interest on this money must be included. If the route is only a mile long and there is only one vehicle, making ten trips a day, then for every trip the expense at six percent on the overhead line investment would amount to nearly 12.5 cents. It is quite evident that this is an element which must be carefully considered.

If we double the number of vehicles per mile of line, with other conditions unchanged, the expense for the overhead per mile of operation is halved; if we quadruple it, the expense per mile is one quarter, and so on. It is thus a question of frequency of service which is going to determine what the use of electric power will cost, and whether it will be cheaper than gasoline.

From the foregoing fundamental considerations, it is seen:—(1) that the size of our vehicle must be determined by careful consideration of the traffic conditions; (2) that the construction and weight is a function of the traffic conditions, the materials selected and the nicety of design; (3) that the selection of the type of roadway has a direct effect upon the power consumption and cost of electrification, and also that the selection of the best type is dependent upon the local conditions and traffic; (4) that the selection of the proper motive power is a direct function of the traffic conditions.

"Well", I can hear some reader remark at this point, "it seems to me that with all your talk you have not gotten very far, for apparently the size, weight, construction and motive power of our vehicle, and the very roadway it runs on depends almost entirely upon the local conditions."

If this is your conclusion, then this article has not been written in vain, for that is exactly the idea which the writer wanted to convey by outlining the fundamentals which must be considered. We can conduct profound researches, and compile yards of statistics a to which is the best, the bus, the trackless trolley or the traction car, and we will never find an answer, becaus there is no such thing as a best which will fit all conditions. We might just as well argue as to which is the best kind of dog; a bullpup, a setter, or a greyhound. There is no direct answer, it all depends on how yo want to use the dog.

While there is no direct answer to this question, careful consideration of the various factors entering into the problem by many authorities enables us to lay down certain general statements as to the form of vehicle which will give the most economic operation under certain service conditions. Broadly speaking, if we are dealing with a district where the traffic conditions are light and the roads passable, a vehicle running on the public highway and driven by a gasoline engine is the cheapest power vehicle to employ.

When the traffic becomes a little heavier, the saving in cost of power by the use of electricity will warrent stringing a pair of overhead wires and using this form of propulsion, but continuing to run on the highway. It can be shown that this change is economically warranted under present conditions, when the service requires the operation of vehicles at slightly less than one hour headway.

When once we have installed the electrically-operated vehicle, it will be the cheapest form to take care of a very considerable increase in the traffic conditions. In fact, assuming that the transportation company is not put to any expense for maintaining the highway, the frequency of service will have to increase to a point where vehicles are operated at a headway somewhere in the neighborhood of five minutes, before it will pay to install a track. These are broad general statements which existing local conditions in special cases may modify, but represent rather closely the actual limitations.

To sum up, let us look at this whole problem from a broad standpoint and not allow ourselves to stray off into side paths where detail considerations are magnified to undue proportions. Power brakes or hand brakes, automatic doors or non-automatic, high or low step, etc. are all matters which must be considered, but these are details which apply to the vehicle, whether it runs on a track or on the highway, whether it is propelled by electricity or gas. Custom and evolution at present have tied up certain forms of construction and conveniences with a given method of operation, bu eventually only those which are best and essential fo the service conditions will survive.

A Slip Arrester for Heavy Electric Locomotives

C. C. WHITTAKER
Railway Equipment Engineering Dept.,
Westinghouse Electric & Mfg. Company

SINCE maximum power is obtained from a locomotive at the moment just prior to the slipping of the driving wheels, it is of advantage to work a locomotive at this point, especially when accelerating a maximum tonnage train. An ideal arrangement would include a device which could foretell the exact condition of the rail, as regards coefficient of adhesion, and which would prevent the locomotive from being accelerated at a rate which would cause slipping. The nearest approach to this ideal is found in a device which automatically removes torque from or decreases it, on the axle slipping, the instant after slipping occurs, thus allowing the drivers to grip the rail again so that the acceleration may continue.

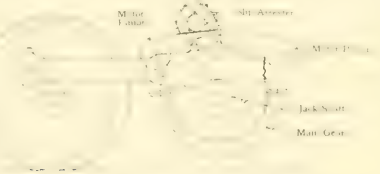


FIG. 1—METHOD OF APPLYING SLIP ARRESTER

The device herein described functions on the first accelerative impulse given the drivers by the stored energy in the stressed parts. Fig. 1 shows one method of applying the slip arrester to a locomotive where the driving axles are driven by means of side rods from a jackshaft. The arrester is mounted on an overhanging bracket, bolted to the locomotive side frames.

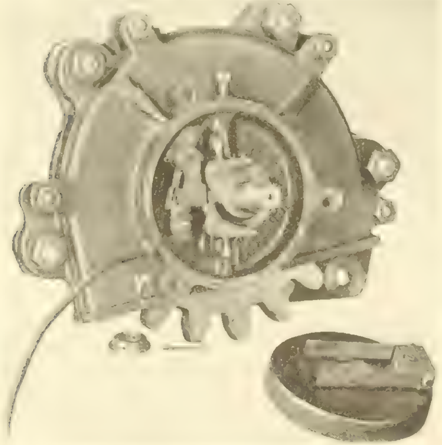


FIG. 4—[illegible] ARRESTER

The detail elements are shown in the simplified sketch, Fig. 2. The device is driven by a narrow face pinion which meshes with the main gear on the jackshaft, through an opening in the top of the gear case. A shaft is pressed into this pinion and it supports the whole weight of the device on two ball bearings. A spider pressed onto this shaft carries an insulated slip ring. The spider and slip ring each carry a contact stud *A* and *B*. These contact studs each press against a flat spring, the far ends of which are in metallic contact with each other, but are insulated from an "inertia disc" having a bearing fit on the shaft.

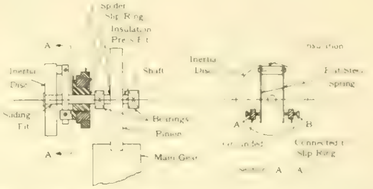


FIG. 2—DETAILS OF ARRESTER IN NORMAL POSITION

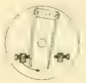


FIG. 3—SPRINGS DEFLECTED

When the locomotive accelerates in a normal manner, without the drivers slipping, the pinion causes the device to rotate. One contact, *A* or *B*, depending upon the direction of rotation, by its pressure against its adjacent flat spring, causes the inertia disc to rotate with the rest of the assembly. Whenever the arrester is accelerated suddenly, the disc, due to its inertia, will lag behind and deflect the flat spring, as shown in Fig. 3.

The contacts *A* and *B* have a certain amount of initial tension, so that an appreciable deflection takes place on one spring before the other leaves its contact. This tension can be varied to suit the maximum rate of acceleration desired. The action of the device is independent of speed, but functions whenever a predetermined rate of acceleration is exceeded.

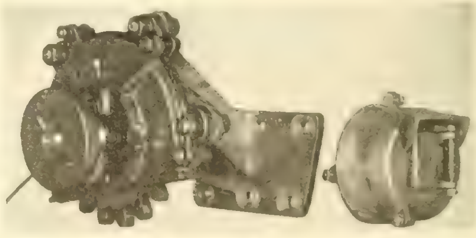


FIG. 5—ARRESTER ASSEMBLED WITH END COVERS REMOVED

As long as neither of the contacts *A* or *B* break contact with their springs, a low-voltage electric circuit is maintained through a relay mounted in the cab, in series with contact *B*, through the two flat springs to contact *A* and thence to ground. As long as this relay circuit is maintained, power may be applied to the main motors in the usual manner, but the instant this circuit is opened, even if momentarily, power is cut off from the truck whose drivers are slipping, and cannot be again applied until the amount of power to be supplied has been reduced to a value less than that which caused the slipping.

Fig. 4 shows an end view of the complete arrester with the inertia disc removed, so that the brushholder with brush bearing on the slip ring, and contacts *A* and *B* can be seen. Fig. 5 shows the arrester assembled with the overhanging bracket and with end cover removed. The door in the side of the cover is to permit ready access to the brushes for inspection.

If slipping occurs during regeneration, the retarding effort of the locomotive is not sufficient to hold the train and it should be aided by an application of brakes on another locomotive which is not regenerating, or by an application of train brakes. Under these conditions, the slip arrester would be rendered inoperative.

The arrester is constructed very substantially to withstand the severe vibration to which its position on the locomotive subjects it. Its weight is 75 pounds. One arrester is required for each truck on a locomotive with side rod drive, and one for each axle on a locomotive having quill drive.

Methods of Hiring and Training Men

Used by the Mechanical Department of the Kansas City Railways

HENRY S. DAY
Equipment Engineer

IF THE operating man was questioned as to what most concerned him today in the operation of his property, his reply would probably be "Labor turn over". While this may or may not be the most vital question, there is no doubt that it is a gravely important one, particularly to the departments that require specialized and skilled labor, and adds tremendously to the expense of operating a department, as well as contributing to a high degree of inefficiency.

After a careful study of the department of which the writer is in charge, it is believed that one hundred dollars is a conservative estimate of the average cost to the department for every skilled or semiskilled workman replaced by a new one. It is not intended here to open a discussion as to the causes leading up to a labor situation different than has ever before confronted the street railway official, but to set forth the more important steps that have been taken to create a more stable condition.

It will undoubtedly be admitted that the labor situation at present is different, and if conditions or a semblance of the conditions that prevailed three or four years ago are to be regained, extraordinary efforts must be put forth. It is difficult to overcome and rectify a bad condition unless the causes are known, and in seeking for the cause of a high labor turn over it was hard to find anything but generalizations to work on. No two men gave the same reason for quitting after a short term of employment or, if they did, the reason was vague and unsound. Also the men who continued in the Company's employ seemed to lack initiative and interest. These two facts suggested that whatever the causes were it might be possible to create the desired results by first selecting, as nearly as possible, the right kind of men, and after selecting and hiring these men, educate them along the lines that would obtain results, both for the Company and the man. This idea was something definite to work on, and it was therefore decided that every prospective employee would be carefully interviewed, that no employee would quit the department without having his case discussed, and that well-considered efforts would be made to educate both old and new employees.

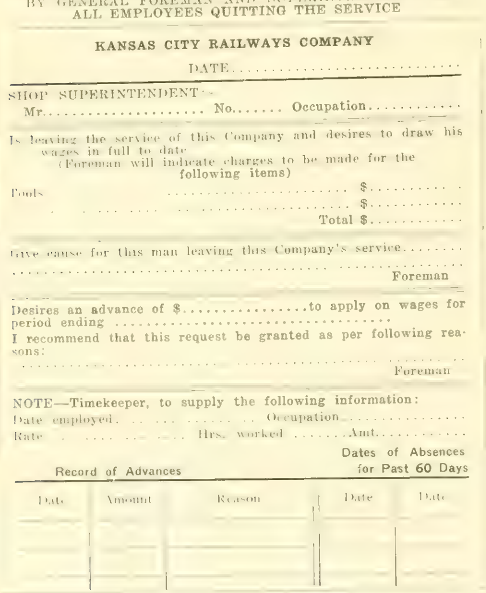
An analysis of present records seem to indicate that not sufficient care was exercised in selection, or the new employee, when hired, was not properly informed regarding the organization he was entering and that, once hired, he was not properly handled. In other words, the job was not properly "sold" to the workman and the foreman was not properly trained to obtain production in his department and at the same time hold his men. Records show that 95 percent of the men leaving the department do so before the expiration of six month's service, and the great majority of these before three months.

Wages and shop conditions being equal, there is no sound reason why a workman should be satisfied to wander from one shop to another unless he believes he is bettering his condition, and if he has been properly sold his position at the time he was hired, he may not be so quick to leave it and seek another one. By "selling" the position is meant that, in an interview with the Superintendent or department head the new position is described in full, including the duties he will be required to perform, the possibilities for advancement and promotion, the policy of the Company in handling promotions, the advantages of working for a concern whose management pursues a fixed policy of offering a fair day's wage and fair working conditions for a fair day's work, and above all that the workman himself will benefit by increased wages and better working conditions in a just proportion as his individual efficiency increases the efficiency of the shop or department as a whole.

If such an interview has taken place and has been successful to the point of convincing the new employee that he is entering a service that is truly co-operative, and that it is a fact that the greater percent of labor turn over takes place during the first six months, then it is fair to assume that if the employee is properly handled he will hold the new job.

This leads up to the point that, before starting to train the man, the foreman must be carefully trained. All of the foregoing has slight reference to the training of men, but you cannot train men until you get them and after getting them, keep them. If before a man is actually placed on the pay roll, applications are carefully gone over and as near as possible the right men selected, by questioning as to former positions, fitness for the new position, the distance to be travelled daily to and from work, tendency toward radicalism, whether he is a native of the town, if his family is located in the town and a great many other questions of like nature, a great many men will never be hired, as it will be evident from the information thus gained that they will not be contented for any length of time and, if hired, will leave in a few weeks or months.

FORM I—FILLED OUT BY FOREMEN AND COUNTERSIGNED BY GENERAL FOREMAN AND SUPERINTENDENT FOR ALL EMPLOYEES QUITTING THE SERVICE



KANSAS CITY RAILWAYS COMPANY

DATE..............................

SHOP SUPERINTENDENT—
Mr...................... No....... Occupation............

Is leaving the service of this Company and desires to draw his wages in full to date
(Foreman will indicate charges to be made for the following items)

Tools .... $...........
.... $............
Total $............

Give cause for this man leaving this Company's service........
....
Foreman

Desires an advance of $................to apply on wages for period ending ....
I recommend that this request be granted as per following reasons:
....
Foreman

NOTE—Timekeeper, to supply the following information:
Date employed.................. Occupation ....
Rate .... Hrs. worked ....Amt............

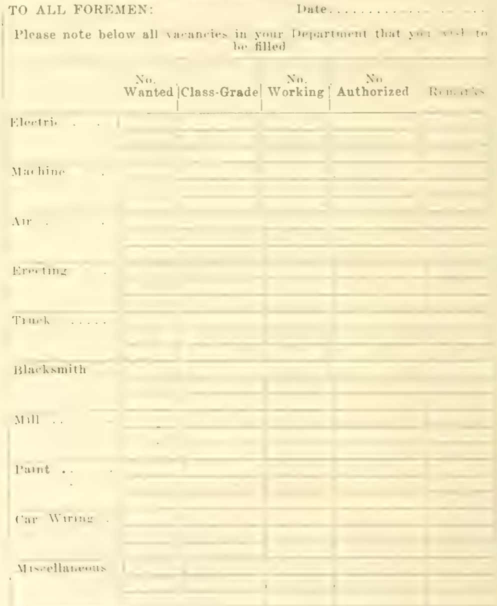
Record of Advances			Dates of Absences for Past 60 Days	
Date	Amount	Reason	Date	Date

If, then, all possible care has been exercised in the selection of the new employee and proper interviewing him at the start, we come back to the first six months of service and the handling of the man during that period.

In the past, about the only qualifications generally considered for a foreman was a little greater skill, better application, a record for being on time or some like quality, and a man was taken out of the ranks and given the supervision of a greater or less number of men. Little or no study was made of the man at the time of his promotion or after, as to his ability to handle men, when as a matter of fact the foreman is the only man who comes in direct contact with the workman and from whom the workman forms his ideas of the Company and its policies.

It makes no difference how anxious the management is to co-operate with the workman or to have the workman co-operate with the management, an untrained foreman will do more to retard progress and promote inefficiency and labor turn over than any other factor in the personnel of an organization. By this is not meant that the average foreman is not a capable mechanic, but that he simply has not been trained to oversee men. His principal idea is production and he sees the results of the man's work and not the man, and does not seem to realize that, if the man is properly handled, the production is bound to follow. It is assumed that the foreman is a capable mechanic and that he is generally intelligent and ambitious; if he is not he should not be a foreman.

FORM II—SENT TO FOREMAN DESIRING TO REQUISITION NEW MEN



TO ALL FOREMEN: Date..................

Please note below all vacancies in your Department that you wish to be filled

	No. Wanted	Class-Grade	No. Working	No. Authorized	Remarks
Electric					
Machine					
Air					
Erecting					
Truck					
Blacksmith					
Mill					
Paint					
Car Wiring					
Miscellaneous					

In the present instance the plan for training foremen is not elaborate and no prepared course or text books are used. Weekly meetings of all foremen in the department are held in which the head of the department acts as chairman. These meetings are for the purpose of discussing ways and means of carrying on the work, but a certain amount of time is devoted to talks and open discussions on the duties of a foreman. He is frankly told he is the key man in the organization, and on his shoulders more than on any others rests the success of the department. He is impressed with the fact that his job carries a distinct dignity and importance, and that he is a good long step ahead of the men under him. He is taught to plan his work, and show from day to day and week to week that he is turning labor and material into dollars and cents.

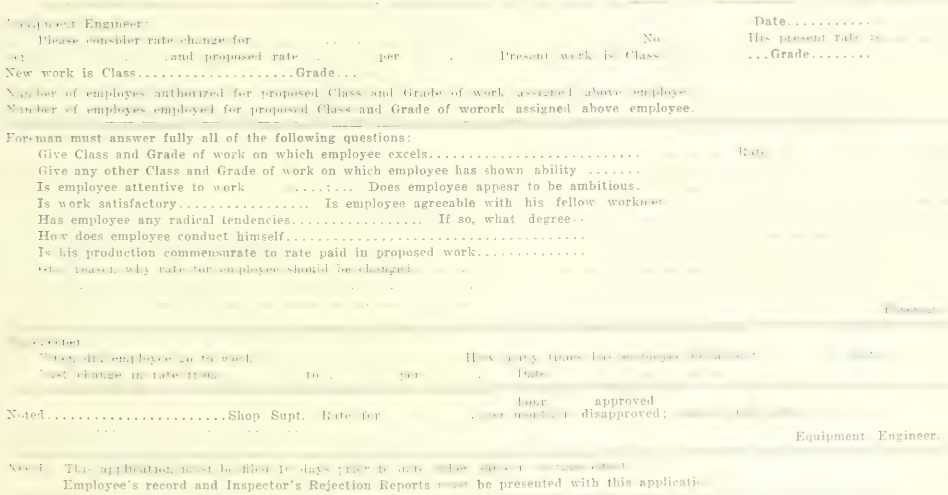
Attendance at these meetings is compulsory and the meetings are held on the Company's time. The foreman is asked to criticise the system and methods and made to feel that his opinion is valuable and needed. The daily, weekly and monthly performance of the department, as well as the output, car failures, labor turn over, etc., are charted and he is instructed in the use of the charts and the importance of progress reports and shop schedules are hammered home every meeting. Once each week a report of the labor turn over in his particular department, as well as the whole department, is sent to each foreman, so that he can see at a glance how many men have been hired, left the service or have been late, the number of hours scheduled and lost, and the names of the men. He is given to understand that all department records and costs are open for his inspection, and he is instructed to familiarize himself with all costs. It is intended that he will eventually know, in dollars and cents, what the individual operations under his supervision amount to and the total expense of his own department.

As much as possible all paper work is taken out of the foreman's hands and all equipment records, records of tests, etc., are kept in the office, so that once the work on a car is completed or a job finished, he is not further concerned and can devote his mind and energies to his new and unfinished work. No foreman is allowed to interview or hire new men, this being done by the superintendent of shops or car barns or the department head. Each foreman is given a list of the maximum number of men allowed his department, the list showing the maximum number of each class, grade and rate, and this list is at all times kept up to date. In order to keep his full complement of men and fill vacancies, each foreman enters on a form daily received from the office, the number of men he is lacking, giving the class, grade and rate, and these lists are consolidated by the chief clerk who, in a preliminary interview, selects applicants in accordance with his consolidated list for an interview by the superintendent or department head. The new employee is then turned over to the foreman and he is expected, at the end of a week, to know if the new man is suitable for the position he has filled, although, if he is still in doubt but inclined to the belief that the new man may make good, the time is extended some few days longer, the point being made that the forman is responsible for the continuance in the service of an unsuitable man.

The idea of passing a new employee down from the head of a department to the foreman is reversed in the case of a man being discharged or resigning. No foreman can discharge an employee. In the event of an employee leaving the service, the foreman fills out and signs a prescribed form, stating the reason, and this form must be signed by the General Foreman and Shop Superintendent before it reaches the department head whose signature is necessary before the man can obtain his pay. This gives ample opportunity to discover why the man should or should not be let out or, if desired, to discuss with him the advisability of quitting the service. This does not reduce the foreman's authority, but does eliminate any chance of unfair treatment, and frequently straightens out unnecessary tangles and continues desirable men in the service.

The criticism may be made that a department head has not the time at his disposal to become an employment agent. On some of the larger roads this may be true, but on these roads there are always competent men

FORM III- APPLICATION FOR CHANGE IN RATE



Equipment Engineer: Date...........

Please consider rate change for ... No. His present rate is

[illegible] .and proposed rate . per . Present work is Class ...Grade........

New work is Class....................Grade...

Number of employes authorized for proposed Class and Grade of work assigned above employe

Number of employes employed for proposed Class and Grade of worork assigned above employee.

Foreman must answer fully all of the following questions:

Give Class and Grade of work on which employee excels.......................... Rate

Give any other Class and Grade of work on which employee has shown ability ....

Is employee attentive to work ....:... Does employee appear to be ambitious.

Is work satisfactory................. Is employee agreeable with his fellow workmen.

Has employee any radical tendencies.................. If so, what degree..

How does employee conduct himself...

Is his production commensurate to rate paid in proposed work..............

Give reason why rate for employee should be changed

Foreman.

Record

When did employee go to work How many times has employee [illegible]

Last change in rate from to per . Date

Noted.......................Shop Supt. Rate for [illegible] per hour approved disapproved;

Equipment Engineer.

Note: This application must be filed 10 days prior to date [illegible]

Employee's record and Inspector's Rejection Reports must be presented with this applicati for this work and there seems nothing of greater importance at this time.

In order to work up "esprit de corps" a Foremen's Association was formed which meets once each month. This Association includes every foreman, assistant foreman and all inspectors in the department. A president, vice-president, secretary and treasurer with an entertainment and an educational committee were elected, and the meetings generally consist of a dinner and smoker followed by carefully selected papers along the lines of shop planning, proper inspection methods, etc. These meetings have done much to create a spirit of co-operation and good fellowship, and have also been valuable from a purely educational standpoint.

FORM IV—WEEKLY LABOR STATEMENT ISSUED TO ALL DEPARTMENT SUPERINTENDENTS, FOREMEN AND ASSISTANTS

A copy of this form is sent to the General Manager

LABOR STATEMENT for week ending

DEPARTMENT

		PUT ON				QUIT							DISCH'D						DISTRIB'N									Length of Service								
																			Hrly		Sal															
DEPARTMENT	Number of Employees First of Week	New	Reinstated	Transferred	TOTAL HIRED	Transferred	Shop Conditions	Living Conditions	Sickness	Laid Off	Better Position	TOTAL QUIT	Incompetent	Insubordination	Irregular Att	Violation Rules	TOTAL DISCHARGED	Number of Employees Last of Week	Productive	Non Prod	Productive	Non Prod	Hours Scheduled	Hours Worked	Per Cent of Attendance	Per Cent of Productive Labor	Per Cent of Labor Turn-over	Over 5 Years	Over 4 Years	Over 3 Years	Over 2 Years	Over 1 Year	Over 6 Months	Over 3 Months	Over 1 Month	Under 1 Month
SHOPS																																				
Electric																																				
Machine																																				
Blacksmith																																				
Truck																																				
Air Brake																																				
Erecting																																				
Mill																																				
Car Wiring																																				
Paint																																				
Miscellaneous																																				
Office and Supervisor																																				
TOTAL																																				
DIVISIONS																																				
15th and Harrison																																				
[illegible] and Brighton																																				
18th and [illegible]																																				
2d and Manchester																																				
3d and Holmes																																				
10th and [illegible]																																				
[illegible] Avenue																																				
Supervision																																				
TOTAL																																				
GRAND TOTAL																																				

Coming back to the man again, as soon as he is selected, interviewed and hired, it is endeavored to place him under a careful follow up system, both by foremen, inspectors and superintendents. The way in which this company does certain work is shown him and a reason given, so that, as nearly as practicable, standard rules and methods shall be followed. Each new employe is given a letter that tells him what his hours are, his clock number, his class, grade and rate, the department in which he has been hired, his foreman and all other officials' names and like information. In other words, he is given a typewritten letter that gives him in accurate and concise form information that frequently requires days or weeks to acquire, and which quickly puts him in touch with the organization he has entered.

For the very reason that labor turn over was high, with a resultant low efficiency, it was believed that a school of instruction, if a sufficient number of men could be interested, might improve the efficiency of the department. The results already obtained have justified the time and expense, and a more thorough and elaborate program is planned for this coming winter. In planning such work, the fact that many car and equipment failures are due to poor repairs and poor inspection is kept in mind.

A room in the shop was equipped with an enlarged wiring diagram of a K control and sample motors, controllers, and trucks were arranged so that a demonstration could be made. In selecting the apparatus for demonstration, equipment in bad condition was utilized and thoroughly competent inspectors or foremen made repairs and adjustments before the men, and showed them how to do it in the right way. Pieces of apparatus improperly repaired or inspected were brought to the instruction room and there repaired in the correct method, each step being carefully demonstrated. Poor cable splices were removed from cars and with new pieces of wire the proper way to splice and solder wire was shown. Journal boxes and armatures and axle bearings were properly packed. An air brake test rack was set up, with piping painted to a color scheme which was duplicated on enlarged charts, showing piping and cross-sections of valves. These pipes were used to show pipe line and valve passages, with the pressure and volume of air, and the various applications and reductions were demonstrated on the test rack. Actual cases of trouble occurring on cars in the street were reproduced in the instruction room, and the causes demonstrated and explained.

The instructions are strictly along practical lines and as much as possible technicalities and theories are kept in the back ground, although it was found that explanation of simple theories seemed to arouse interest in men from whom it was least expected. Men who had been around cars for years and were generally spoken of as good men, were found to have the vaguest ideas of electrical circuits, and few had any real ideas of the theory of air brakes. Enlarged prints of air brake installations were supplied to the men engaged in air brake inspection and repairs, with instructions to fill in the color scheme, and colored master charts were hung in the instruction room for the purpose of comparison. The enlarged diagram of a K control 15 by 15 ft. with lamps to represent controller and reverser contacts, field coils, and armatures, was wired in with a controller, using red lamps for the reverse positions, this means being used to demonstrate wiring diagrams and teach the proper method of testing out circuits. At these instruction periods no opportunity was lost of showing the importance of careful and thorough work and the seriousness of any car failure both in delay to service, as well as dollars and cents loss to the company.

FORM V—LABOR DATA FOR WEEK ENDING AUGUST 6, 1920

Department	No. Men Working July 30th	Addition to Force	Left Service	Discharged	No. Men Working Aug. 6th	Hours Scheduled	Hours Lost	Per Cent of Attendance
Electric ...	44	1	2	0	43	2 199	183	91.7 %
Machine ...	55	2	3	0	54	2 763½	241½	91.3 %
Blacksmith .	24	3	1	0	26	1 242	154	87.6 %
Truck	31	2	0	0	33	1 671	183½	80.2 %
Air Brakes	14	1	0	0	15	723	4½	99.4 %
Erecting ..	50	1	0	0	51	2 559	105	95.9 %
Mill	11	0	0	0	11	561	18	96.8 %
Car Wiring and Assembly	12	0	0	0	12	612	35	94.3 %
Paint	21	3	1	0	23	1 133	77½	93.2 %
Miscellaneous .	35	1	4	0	30	1 620	199½	87.7 %
Total ...	297	14	11	0	298	15 083½	1 201½	92.15%

LENGTH OF SERVICE

Over 1 Year	Over 6 Mos.	Over 3 Mos.	Over 1 Mo.	Under 1 Mo.
3	4	1	1	2

Total—11

The period of instruction was arranged to make the work interesting, snappy and not long enough to allow interest to drag. Different demonstrations and talks were held for different groups, so that a man interested in trucks and brake rigging would not have to listen to a discussion on the proper way to adjust a controller finger, and thereby become bored.

Of necessity this instruction is given off the company's time, and the success of the scheme depends on awakening each man's interest and conveying to him the idea that he is getting something that will increase his efficiency, and consequently put him in the way of promotion and increased earning capacity. When the school was started the attendance was larger at first than was maintained later, as a good many came out of curiosity, but enough continued to come to make it worth while.

Altogether the idea has worked well and not the least of the benefits obtained is the fact that the men bring in and freely discuss a great many points in the daily routine that would never be brought out except under similar circumstances. Many good suggestions have been received and many annoying little conditions straightened out, due to a general discussion and frank criticism, that all help to improve the general efficiency of the department.

FORM VI—INSTRUCTIONS FOR NEW EMPLOYEES

Date

Mr.

You are engaged for [illegible]

Grade [illegible] work at [illegible] ....c per hour [illegible]

[illegible] Dept. under Mr.

Foreman. Your clock number is [illegible] locker number

You will start work at 7:00 A. M. [illegible] 12:30 P. M. and stop at 5:00 P. M. on all days except Saturday, when you will start at 7:00 A. M. and stop at 1:00 P. M. You will punch your number on the time clock before starting time in A. M. and after leaving time in P. M. Your total working hours will be fifty-one hours per week but [illegible] fifty-two and one-half hours if you are not absent or late during the week. Overtime, Sunday and Holiday work is paid for at the rate of time and one-half. You will be paid on the 11th and 26th of each month. The company holds [illegible] pay in order to make up the pay rolls.

If unable for any reason to report for work you will send word to the office or telephone (Bell 'Phone Clifton 624; Home 'Phone Benton 2459).

You will receive an employees' book of tickets free in which there are seventy two tickets, and in which you will write your name, and you will receive a [illegible] each month from the Timekeeper. These books are good for yourself **only** and no one else.

Twice each month, on the day before pay day you will receive an identity slip from Mr. Woodward, the Timekeeper, which you will present for your pay to the Paymaster at the [illegible] pay car, which comes to the Shop.

Days on which identity slips and employees' tickets are issued will be advertised on bulletin boards. You are expected to keep yourself familiar with notices and bulletins posted on Shop Bulletin Boards.

The Shop is operated on [illegible] Employees' Representation Committee, elected by the men, consisting [illegible] Mr. Roberts, Mr. [illegible] Mr. Spears, Mr. Jobes. Six foremen: Mr. Lamkin, Mr. Hibbert, Mr. West, Mr. [illegible] General Foreman, Mr. [illegible]

If you should believe your conditions in the Shop are not satisfactory, you should report them to your Foreman or the Committee. You are invited to make criticisms to create better working conditions and greater efficiency and safety.

[illegible] of the Service," which is attached to these instructions, and [illegible]

As an employee of this Company you are eligible for membership [illegible] Association. Your Foreman will gladly give you full information on these.

FOLLOWING IS A LIST OF THE [illegible]

[illegible]

Mr. E. Tulley, Electric Department Foreman
Mr. A. Hibbert, Mill Department Foreman

It is appreciated that many of the ideas mentioned are not new, but the consistent carrying out of the general scheme outlined has shown results and the results are steadily growing better. Welfare work, in the sense generally conveyed by that term, has been kept out of the plan, on the ground that the right kind of American workman prefers to earn and pay for his own doughnuts and coffee. The accompanying forms and charts are the principal ones used in tabulating the labor situation and the titles are self-explanatory.

Expanding Bronze Bearings

C. M. CROSS

Motor Engineering Dept.,
Westinghouse Electric & Mfg. Company

When a bearing becomes loose in a railway motor housing, it should be repaired before the wear becomes so great that the bearing will have to be scrapped. Bronze armature bearings, if not too loose in the housings, may be reclaimed by expanding.

The most prevalent cause of looseness is the removal of bearings for rebabbitting and replacing them without expanding. When a bearing shell is pressed out, the small ridges due to turning are smoothed out, so that the tonnage required to press it in again is much reduced, as well as the amount of press fit. It is a much safer proceedure to expand the shell when it is removed the first time.

Some shells may be expanded a second time, but the percentage breakage is high, approximately 75 percent. However, it is economy to scrap a shell rather than to allow the housing to wear due to loose bearings, necessitating reboring the housing and using a special over-size bearing.

The following method of expanding bronze bearings has been found to work satisfactorily in the majority of cases. It should be borne in mind at the outset that satisfactory expansion depends upon having a good grade of bronze, properly mixed and poured. If the bronze has been overheated when the old babbitt was melted out, a fracture of the shell is liable to occur.

CLEANING

When a bearing is received for expanding, all oil, dirt, or foreign substances should be removed by dipping in a solution of caustic potash or by burning. Burning should be continued until all smoke ceases, taking care to heat the shell uniformly, and avoid a temperature that would cause the babbitt to run. Scrape the surface with a file and clean with rough sand paper.

TINNING

Remove the old babbitt by heating, preferably in a pot of scrap babbitt. Great care should be used not to allow the bearing to remain too long in the babbitt pot, as the surface to be babbitted will not only be oxidized, destroying the tinned surface, but the bronze will be weakened, making it much more subject to breaking when being expanded. It is better to immerse the shell for 10 or 15 seconds, withdraw it, and see if the babbitt runs, repeating the immersing for shorter lengths of time until the old babbitt has been removed, and a bright, tinned surface appears.

Should the shell be overheated and the surface oxidized, or if the shaft has worn through the babbitt into the brass, it may be necessary to take a light cut to present a clean surface to be tinned, otherwise the babbitt would only adhere in spots.

Where it is necessary to retin, proceed as follows:—Protect the parts not to be tinned by painting them with a thin mixture of graphite and water. When this is dry, swab the parts to be tinned with zinc chloride, then dip the shell into a pot of half and half solder, which should be kept at a temperature of not less than 340 degrees and not more than 375 degrees C. Leave the shell in the solder until it is just hot enough for the solder to run off, leaving a thin coating. Remove the shell from the pot and rub the surface to be coated thoroughly with a swab, saturated with zinc chloride, then dip in solder again to wash off all traces of zinc chloride. If any untinned spots can be detected on the surface to be babbitted, repeat the operation.

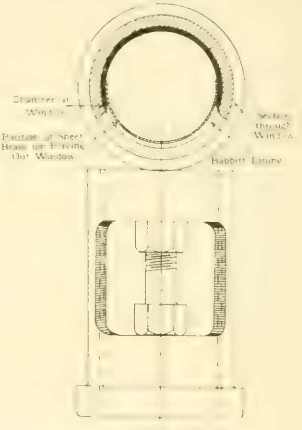


FIG. 1—SKETCH OF BEARING
Showing tack in window

BABBITTING

Shells should now be babbitted with approximately a 3/16 in. wall. This allows a roughing cut of 1/16 in., leaving a ⅛ in. wall when the bearing is expanded, and an opportunity to finish to a 1/16 in. wall when the bearing is finished.*

EXPANDING

The expanding is accomplished by forcing a tapered mandrel through the shell, by means of a hydraulic press. Mandrels are 8 to 12 in. long and made from sections of shafts of axle steel, with a taper of 0.030 in. to the foot. A four inch bearing will require from one to five tons and a six inch bearing from five to ten tons pressure, depending on the amount of babbitt, the thickness of the walls and the condition of the metal in the shell. It is well to oil the mandrel before pressing it through the bearing. The shell should have the bore turned to the same diameter as the small end of the tapered mandrel, the mandrel having a 1/8 in. radius fillet to avoid cutting the babbitt.

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*More complete information relating to the babbitting of [illegible] bearings may be found in "Railway Operating Data" section of the Journal for October, 1910.

In bearings where the window covers one third the circumference or more, a jack should be used between the sides of the window in an axial direction to keep the small section from being pressed out of shape. A 3/4 in. bolt and nut answer very well for this jack.

The bearings are mounted flange down on a plate with a hole large enough to allow the tapered mandrel to pass through. When the mandrel has been pressed through, the bearing is calipered to see if it has stretched in an oblong shape due to the metal stretching more at the window. To overcome this, a sheet of brass, (of a thickness equal to the difference between the maximum and minimum inside diameters of the shell, approximately 0.010 in.) is placed in front of the window for the full length of the bearing, having about a one inch lap on each side of the window, and the same mandrel pressed through again. This brings the bearing to approximately a true cylinder.

FINISHING

The inside diameter should be carefully bored to the shaft size plus 0.006 to 0.008 in., the sides of the windows chamfered, and bearing mounted on a mandrel or expansion chuck for the final finish of the outside diameter. When expanded, the bearing should be from 0.010 to 0.020 in. too large so that a light cut can be taken, leaving it from 0.002 to 0.004 in. larger than the normal size for pressing in the housings.

GENERAL

While this method has given satisfactory results for small expansions, it cannot be used as a cureall for loose armature bearings, as a net expansion of over 0.010 to 0.015 in. would weaken the bronze, if not rupture it. By this method many bronze bearings may be reclaimed which would otherwise be scrapped, and a tight fit maintained between housing and bearing.

SUMMARY

1—Clean bearing.
2—Tin surface to be babbitted, do not overheat.
3—Babbitt bearing.
4—Bore to small diameter of tapered mandrel.
5—Press mandrel through, taper 0.030 in. to one foot.
6—Press out at window, if necessary.
7—Bore for inside diameter finish 0.006 to 0.008 in. large.
8—Chamfer window.
9—Turn outside diameter 0.002 to 0.004 in. large.

Methods of Protecting Electrical Equipments

LYNN G. RILEY
Control Engineering Dept.,
Westinghouse Electric & Mfg. Company

ADEQUATE protection of the electrical equipment on cars and locomotives becomes increasingly important as the distribution system expands in size and capacity. Safety considerations, and the prevention of serious destruction of parts, also justify a careful consideration of the causes of overloads and means for preventing or minimizing the effects.

TROUBLE CAUSES

Some of the conditions which must be guarded against are the following:—

1—Normal overloads, due to careless operation or incorrect functioning of apparatus.

2—Excessive overloads, due to grounded apparatus or cables.

3—Momentary interruption of the power supply, due to bouncing of the trolley or gaps in the third rail, causing current surges and possible flashing of motors.

4—Violent surges in the line voltage, due to sudden changes in the load, particularly at the end of long transmission lines.

5—Grounds occurring between the current collector and the main fuse, which are not sufficiently severe to open the substation or feeder breakers.

6—Failure to concentrate the normal arcing in that part of the apparatus especially designed for such duty.

7—Excessive burning of contacts, with accumulation of gases, resulting from "inching" the car in congested traffic.

PROTECTIVE MEASURES

The problem of protection changes with the size of the equipment and the ultimate power-house capacity, and the methods used can be divided roughly into those adapted to drum-type control equipments, and those used with multiple-unit or remote control apparatus, the latter including heavy cars and locomotives. Some of the methods used to protect drum-type control equipments are given below in the order of their effectiveness:

1—A magnetic blowout fuse, usually of the ribbon type, connected in the trolley circuit with means for expelling the arc to atmosphere. A fuse is selected to blow on a sustained overload of 200 percent.

2—Separate ribbon fuses in each motor circuit, giving full protection, either in series or in parallel, and acting as automatic cutouts for individual motors.

3—A fuse used in conjunction with a hand operated type circuit breaker mounted on the car platform.

Circuit breakers are set to trip on 150 to 175 percent overload.

4—A fuse in conjunction with a remote control line switch provided with an overload relay and mounted beneath the car. The line switch is operated by a control contact device included in the main controller.

5—A combination of the above, together with special means for securing quick response of the line switch in order to relieve the controller drum of the normal arcing duty when shutting off power.

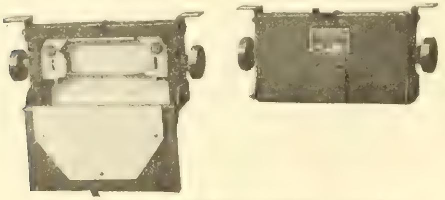
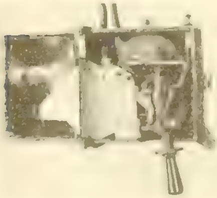


FIG. 1—STANDARD MAGNETIC BLOWOUT FUSE BOX
Using a copper ribbon fuse

It is now generally recognized that all drum controllers can profitably be equipped with a remote control line switch, so connected as to relieve the controller of destructive arcing, and also remove the "fireworks" from the platform. The usual method is to employ a single line switch and overload relay such as shown in Figs. 3, 4 and 6, together with a ratchet switch, Fig. 7, attached to the main controller drum shaft, and connected as indicated in Fig. 8. The ratchet contacts close when the drum is moved to the first position. A pick-up circuit completing the magnet circuit for the line switch is also closed, and immediately by-passed by the *LS* holding interlock. The pick-up contact is open beyond the first position. When moving backward from any position, the ratchet contact opens at once and cannot be closed until moved to the off position. This feature, and the pick-up contact insure that after any interruption of power the car cannot be started again except from the first position.



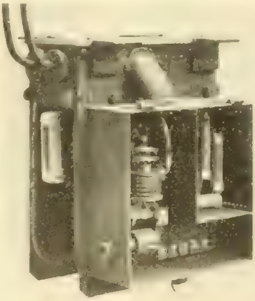
[illegible] for blowout and for trip. One handle closes and trips the [illegible]

[illegible] for use with drum controllers. The overload relay has the automatic reset feature.

The overload relay includes a holding coil which is also energized from the operating circuit and prevents the closing of the line switch magnet circuit following an overload, until the drum controller has been returned to the off position and the control circuit broken. This is known as the automatic reset feature and eliminates the necessity for the manipulation of a separate switch in order to re-establish the operating circuit after the overload has occurred. The possibility of abusing an equipment with such a device is off-set by the time saved in applying power after the overload relay is operated. This feature is especially important in climbing a steep grade.

The methods used for protecting remote control equipments have been carried to a greater degree of refinement on account of the larger sizes of equipments involved. These methods can be summarized as follows:—

1—The standard magnetic blowout ribbon fuse, connected in the trolley circuit, in conjunction with an overload relay which is effective to open some of the starting switches in the switch group. These switches may or may not have extended arc chutes for venting the arc gases, depending on the size of equipment, the service and the characteristics of the power supply.



[illegible] SIZE
For use with either drum or multiple unit control

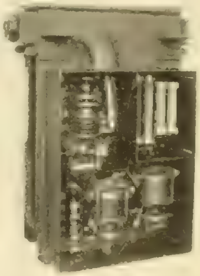


FIG. 5—[illegible] PNEUMATIC [illegible]
The magnet valve is energized from the line, and is so sensitive in adjustment that the switch will open on a sudden drop in voltage, such as may be caused by line disdisturbances or short gaps in the third rail.

2—The combination of fuses and an overload relay, together with a unit switch or switches mounted in a separate frame and acting as a line switch or circuit breaker.

3—A combination of the above, together with two overload relays, one in each motor circuit. Such a combination gives full overload protection, both in series and in parallel, and is especially important in the case of three-speed equipments or on equipments used for both 600 and 1200 volt operation.

4—In conjunction with the fuses and relays, a high-speed line switch adjusted to open with abnormal speed, either in response to the overload relay or due to a sudden drop in voltage, such as usually accompanies a sudden increase in load on the line. A high-voltage surge usually follows such a phenomenon and the purpose of the high-speed is to open the circuit quickly and protect the motors against the voltage peak. Such a line switch is also effective to drop out on a partial interruption of power, such as occurs on a short gap in the third rail.

5—A combination of fuses and a circuit breaker of abnormal speed, which is closed by normal electro-pneumatic means, but is latched in a closed position and the operating mechanism immediately released. The overload coil then acts directly on the latch, independent of any overload relays or controlling circuits and mechanism, and the circuit breaker is caused to open very quickly by means of energy stored in springs previously compressed by the operating mechanism.

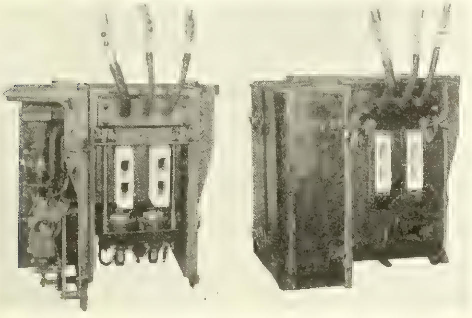


FIG. 6—TWO VIEWS OF A DOUBLE LINE SWITCH
With auxiliary relays, as applied to large multiple-unit cars

6—In high-voltage direct-current service, where the short-circuit current is extreme, the resistance type, multiple circuit breaker is used. A portion of the starting resistance is cut into the circuit before the final circuit breaking switches are opened. The total energy to be dissipated is thus distributed over several switches.

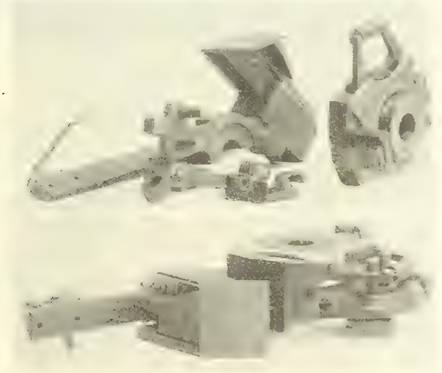


FIG. 7—RATCHET SWITCH ATTACHMENT
For assembly on the bottom of the main shaft of drum controllers. The control circuit for the line switch is opened when the main handle is moved from any point, a short distance toward the "off" position. The ratchet does not close until the handle is moved back to the "off" position stop, and is again advanced to the starting point.

7—On third rail service, there may be used an emergency device to disconnect the entire equipment from the supply circuit, or to trip the feeder circuit breakers, in order to interrupt a high resistance arc.

SPECIAL APPLICATIONS

As illustrating the degree of protection which is found desirable in some special cases, Figs. 5 and 9 show a system of protection which has been applied to heavy multiple-unit equipments. It is desired to have a line switch which will open very quickly on a sudden reduction in voltage, and cause the entire control to open so that power will be applied automatically, with resistance in circuit, after the line voltage has been re-established. In long trains passing over gaps in third rails, violent surging will take place unless some such precaution is provided. The line switch also includes double overload protection, and is provided with exceptionally large exhaust ports in the air cylinder to insure quick operation.

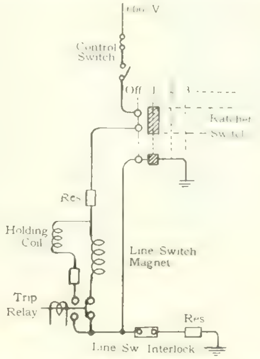


FIG. 8—CONTROL WIRING FOR A LINE SWITCH [illegible] DRUM CONTROLLER RATCHET ATTACHMENT

The train controlling supply is secured from battery voltage, whereas the line switch magnet, as shown in Fig. 9, is operated direct from the 600 volt supply. The line switch magnet circuit is completed through a resistance unit, the operating relay, the overload relay and an interlock which is closed in the starting position only of the main control. As soon as the line switch is closed and the control moves from the first position, additional resistance is inserted in the line switch magnet, this circuit being maintained by the line switch holding interlock. The line switch magnet is thus made very sensitive to fluctuations in line voltage, and may be calibrated to release on a 25 percent reduction. The interlock insures that when the line switch is opened it can not be again closed until the entire control equipment is released in preparation for a new cycle of operation from the starting position. In order to be effective such a switch must open in 0.03 second or less, after the magnet circuit is broken.

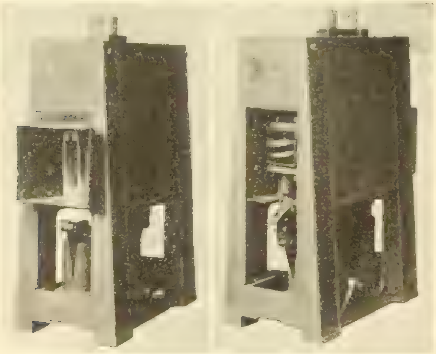


FIG. 10—TWO VIEWS OF A HIGH SPEED DIRECT-CURRENT LOCOMOTIVE CIRCUIT BREAKER

The switch is closed electro-pneumatically, and tripped by a direct acting plunger, independent of the closing mechanism

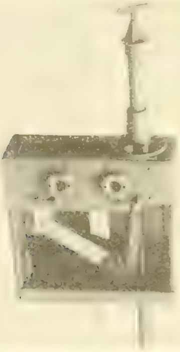


FIG. 11—[illegible]

[illegible] the feeder breakers. Has been applied to third rail locomotives.

In addition to the quick response to fluctuations in line voltage, the quick-acting feature is effective to open ahead of the other switches in the equipment, and relieve them of the arcing duty incident to normal operation.

On heavy capacity, low-voltage, third-rail systems, it is frequently possible to establish a partial ground on cables or other live parts, ahead of the usual disconnection apparatus, resulting in a sustained and very destructive arc. Two methods of extinguishing such an arc are shown in Figs. 11 and 12. The first is a plain knife switch with quick closing means, and is connected directly from the third rail shoe bus to ground. It is effective to open the feeder circuit breakers, whenever the arc itself is not sufficient to do so. Another effective method, shown in Fig. 13, is to fit the third rail shoe beam with an emergency lowering cylinder, combined with the usual shoe-down mechanism in such a way that the contact shoe can be lowered about three inches below the live rail. The magnetic blowout effect of the current in the steel rail is sufficient to open a heavy short-circuit.

SUMMARY

It is obviously impracticable to provide protective equipment on each one of thousands of cars on a large system which is capable of opening any short-circuit which may occur on such a system. However, the ordinary overloads and partial grounds must be taken care of, and the resultant damage to apparatus reduced to a minimum. The degree of refinement necessary is dependent on the size of equipment, the severity of the service, the frequency of operation, and the characteristics of the power supply. Most applications can be governed by previous experience on the property in question or on similar installations.

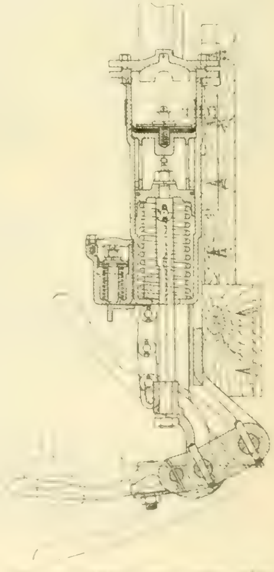


FIG. 12—THIRD RAIL SHOE WITH EMERGENCY LOWERING CYLINDER

The shoe can be pushed down about three inches below the rail [illegible]

On many systems the cost of refinements in protective devices is amply justified by the reduction in maintenance charges, and by the possibility of increased mileage between inspections.

Multiple-Unit Train Operation

S. B. SCHENCK
Railway Equipment Engineering Dept.,
Westinghouse Electric & Mfg. Company

PRESENT day electric traction generally applies motive power to trains in one of two ways. One way is to concentrate the motive power in an individual unit at the head of the train, as is done when an electric locomotive hauls a passenger or freight train. The other way is to distribute the motive power in a number of units throughout the entire train, as for example, a train of passenger cars with motors and motor control apparatus on each car. Each car then constitutes a complete transportation and motive power unit, capable of being operated either alone or in trains. Train operation is made possible by causing the motor control apparatus on all cars to operate in unison, by connecting the apparatus in multiple from operating circuits extending throughout the train. This principle was applied originally on the multiple-unit passenger trains in elevated and subway service, but now the application covers cars and locomotives of the entire electric traction field.

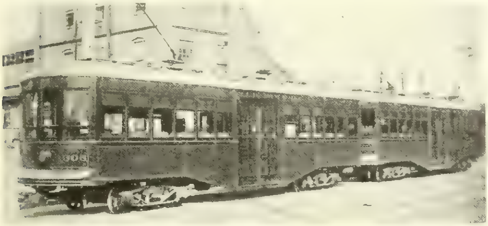


FIG. 1—MULTIPLE UNIT TRAIN FOR STREET RAILWAY SERVICE

Street railways find multiple-unit trains a satisfactory solution of the problem of handling rush hour traffic efficiently. When extra multiple-unit cars are placed in rush hour service, the accelerating rates of the trains do not drop, because the added cars furnish additional motive power, and consequently schedule speeds are maintained. Only one motorman is required per train, thus tending to minimize platform expense. Peak loads originating at one point, such as parks or industrial plants, can be handled expeditiously with trains running under close headway.

On interurban roads or electrified branch lines, the traffic usually has fewer severe fluctuations than occur on street railways. To meet regular schedules the trains must vary in length and many times a single car is sufficient. Multiple-unit equipments fit such conditions admirably. One particular advantage over the use of locomotives is that all the space in the train is available for revenue producing load, and this is a very important item in single car operation or in short trains. The maximum safe speed on some roads is limited by weight of rail, condition of road bed, profile or alignment. When these limits exist, the highest safe speed can be obtained by multiple-unit trains because of the excellent distribution of power and weight.

Multiple-unit train operation is a necessity for elevated and subway lines, due to the extraordinary traffic requirements. Flexibility in proportioning size of train to traffic is one requisite; but above this is the necessity for obtaining close headway and high schedule speeds, which require large motor capacity, high and uniform rates of acceleration and braking. On elevated structures the weight of the train should be well distributed on the rails, and at the same time abundant motive power should be available. Schedules must not be seriously interfered with in case one unit of the trains becomes disabled. Very few of the severe conditions can be met successfully by any type of motive power other than multiple-unit equipments.

On steam railroad electrifications, particularly those handling large volumes of suburban passenger traffic, the conditions are much the same as on subway lines. In addition to furnishing the requisite motor capacity for high schedule speeds and flexibility for handling traffic, the turning of trains at stub-end terminals is eliminated and non-revenue train movements are reduced to a minimum. At congested terminals or yards, the track capacity is utilized to the fullest extent because the motive power is integral with the cars. For these reasons, the multiple-unit car makes an ideal transportation unit for steam railroad electrifications.

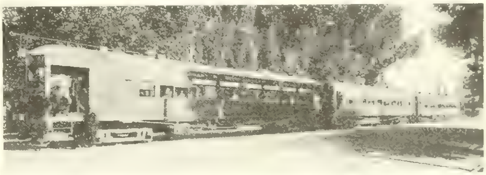


FIG. 2—MULTIPLE-UNIT TRAIN FOR INTERURBAN SERVICE

The principle of multiple-unit control can be applied to locomotives as well as cars. An example of this is found on the New York, New Haven and Hartford Railroad, where two electric locomotives thus equipped are frequently "double-headed" to haul either passenger or freight trains. Another example is the electric freight locomotives of the Norfolk & Western Railroad. Each locomotive comprises two cabs, operated together as one unit, the motor control apparatus of each cab being connected in multiple from control circuits extending from cab to cab.

Besides being adapted for the different classes of service in the electric traction field, multiple-unit control must operate under many widely different conditions. The motor control apparatus on the car or locomotive provides the necessary electrical circuits from the trolley, or other contact conductor, to the propelling motors. The power supply may be alternating or direct current, at voltages ranging from 600 to 3000 for direct current, or 2200 to 16 500 for alternating current. The power supply conductors may have various locations with respect to the running rails, such as overhead trolley, third rail, or underground conductors in open conduit systems.

Some multiple-unit equipments operate on both alternating and direct current, or with various kinds of contact conductors. One example of the latter is found on an interurban road between Baltimore and Washington. On this road the multiple-unit cars run through the city streets, where rail return 600 volt overhead trolleys are required, then over interurban tracks with overhead 1200 volt trolley and rail return; then over a short stretch of track with overhead return and overhead trolley at 600 volts, then through city streets where underground conduit system requires a double contact shoe. This is an unusual combination but it shows the adaptability of the multiple-unit control. This fact is further emphasized by those instances of cars operating interchangeably on both direct and alternating current, and it is all the more remarkable because the greater part of the motor control apparatus is placed in the limited space beneath the car body between the trucks.

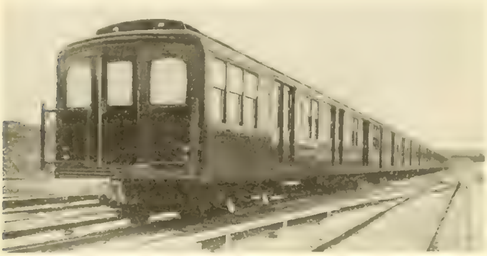


FIG. 3—MULTIPLE-UNIT TRAIN FOR SUBWAY SERVICE

The use of electropneumatic motor control apparatus is one way of meeting the space requirements in multiple-unit train operation. This type of control embodies the results of twenty years development, and the features have all been proved in severe service. Compressed air affords the most reliable means for operating the motor control apparatus. A comparatively large amount of power can be confined in a small cylinder and this power gives positive action of the cylinder piston. When such cylinders are applied to motor switches, the heavy pressures insure good electrical contact. Moreover, the pressure is constant and independent of fluctuations in line voltage. The pneumatic valves controlling the air to the various cylinders are operated electrically by small solenoid magnets which, in turn, obtain their power from control, (or train line), circuits that extend from end to end of each car, and from car to car in a multiple-unit train. The unit construction of switches allows great flexibility in arrangement and grouping of switches in single frames, when required. A cross-section of a typical unit switch group is shown in Fig. 5.

The air pressure requires a very small thrust on the valve stems, so that the power required to operate the valve magnet is small. This allows the use of a storage battery as a source of energy for the control or train line circuits, thus making the operation of the motor control apparatus independent of the trolley voltage, which is a feature of great importance in heavy multiple-unit train operation, such as on elevated, subways, and steam railroad electrifications. The storage battery also serves as a means for energizing emergency lights, signals, markers, and other auxiliary devices, as for instance, electropneumatic air brakes or electropneumatically operated car doors. Reliability of control operation is enhanced by the use of a storage battery, because the low-voltage on the train line control circuits practically eliminates insulation breakdowns. This is an important factor in the design of apparatus used in subways, since brake shoe dust is present in large quantity, and further it becomes magnetized when adhering to certain apparatus and is very difficult to dislodge. High-voltage quickly searches out and breaks down any low resistance path that is made by the iron dust adhering to insulated surfaces.

Another feature in train operation obtainable by the use of a storage battery, is the ability to operate from the head car of the train, if the current collectors on this car are disabled or the power supply is otherwise interrupted. A control system depending on trolley voltage for energizing the control circuits must necessarily be fed from the power supply separately on each car, unless a power bus line is used. If for any reason, the power supply is lost on the head car of a train without a power bus line, the train must then be operated from some one of the rear cars. The result is that the motorman cannot see the track signals to advantage, nor receive the signals from the train crew as quickly, and consequently time is lost, both in starting and in running, which interferes seriously with the schedule of the entire line during rush hours. Since batteries are carried on each car of the train, they are connected in multiple and the chances of failure of control circuit energy are practically eliminated.

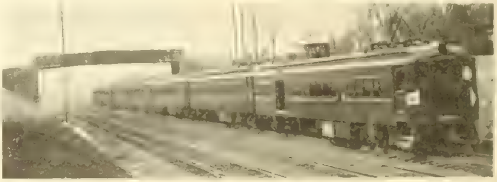


FIG. 4—MULTIPLE-UNIT TRAIN IN SERVICE ON A STEAM RAILROAD ELECTRIFICATION

Cars or locomotives operated from an alternating-current trolley usually require the control circuits to be fed from a source of supply independent of the line voltage, partially because the service usually requires control power to be available at all times, and partially because of the inherently inefficient and complicated design of small alternating-current magnets for controlling the operation of the main motor switches and associated apparatus. When a storage battery is used, it is charged from a small motor-generator set. The battery could possibly be omitted and the motor-generator set used entirely, but in most cases the additional cost of the battery is more than balanced by the advantages of having control energy always available. One particular advantage is in the ease of controlling the spring-raised, air-lowered pantagraph trolleys of a multiple-unit train. If a battery is used, the valve magnets controlling the air cylinders that unlock or lower the trolley can be energized on all cars simultaneously and all trolleys of the train unlocked or lowered at the same time. Without the battery, no power is available from the line when all trolleys are down and consequently an awkward and inconvenient method of trolley control is required. The trolleys on the head car of the train must be controlled independent of those on the other cars so as to furnish power from the line for energizing the control circuits to the trolleys on the rear cars. This requires extra work to be done every time the trolleys are raised or lowered throughout the train.

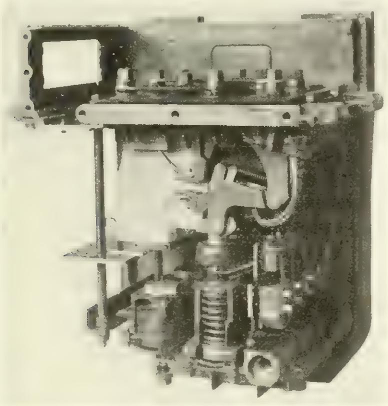


FIG. 5—CROSS-SECTION OF A TYPICAL SWITCH GROUP FOR MULTIPLE-UNIT CONTROL

Operating conditions that require auxiliaries, such as pantagraph trolleys, emergency lights, signals, electropneumatic brakes and similar apparatus, to be operated at all times, regardless of line voltage, are confined largely to elevated or subway lines and to steam railroad electrifications. Storage battery control is best adapted to this service. On city and interurban lines the operating conditions differ widely from the subways, elevated and electrified steam railroads. Space for control equipment is much more limited, auxiliaries are few, shop facilities frequently are meagre, train operation is infrequent and it is not only difficult, but often impossible, to secure a good class of labor for operating and maintaining the equipment. These conditions require the elimination of all possible complications of the control equipment, as well as the sacrifice of some advantages for the sake of maximum simplicity and saving of space, so long as reliability of operation is not decreased.

Maximum simplicity of control equipments suitable for these conditions is derived by taking energy from the trolley line for operating the valve magnets of the motor switches and other main circuit apparatus. At the same time, the voltage on most of the control train line circuits can be reduced to a fraction of the trolley voltage by a special arrangement of the magnet coils and the introduction of a control resistor. This arrangement is embodied in the well known "HL" control, where only two train line wires are subjected to full trolley potential when the control is operated. The other train line wires are subjected to about one-fifth of the trolley voltage, because the valve magnet coils are connected across shunt taps of a resistor that is energized directly from the line potential train line wire. Typical HL connections are shown schematically in Fig. 6.

In heavy duty multiple-unit train operation, the control of auxiliaries frequently assumes an importance equal to the control of the motors. Examples of this are electropneumatic air brakes or electropneumatically operated car doors. The latter is a recent development but, like the air brakes, it directly concerns the safety of the passengers on trains, especially in subway service. Every measure taken to increase the reliability of each link of all the control circuits throughout the train is a step towards increased safety and efficiency. The

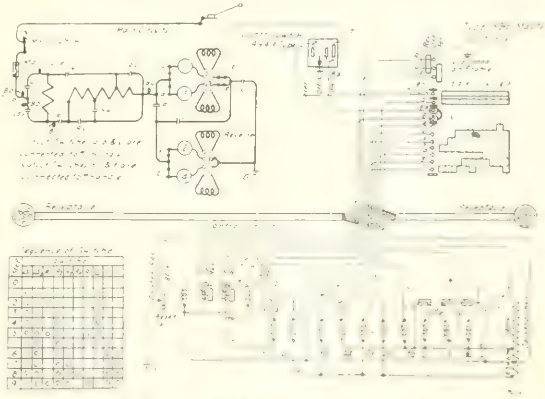


FIG. 6—TYPICAL SCHEMATIC DIAGRAM OF HL TYPE MULTIPLE-UNIT CONTROL

control train line receptacles and jumper that extend the control circuits from car to car present opportunities for improvement. The difficulty in obtaining a receptacle and jumper locking device suitable for all classes of train service, and the increasing number of auxiliaries requiring train line circuits, together with the necessity for simplifying the connections between cars, have been factors leading to the development of various kinds of automatic couplers, so that the operation of coupling cars also makes the connections for the air lines and the control and signal circuits. It is interesting to note that the use of the automatic coupler, together with unit switch magnet valves requiring small power for operation, has made possible the operation of 16 car multiple-unit trains.

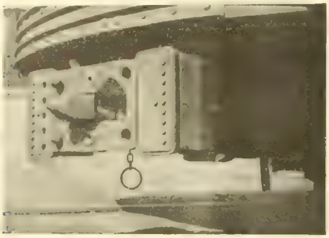


FIG. 7—AUTOMATIC COUPLER ON THE DRAWBAR OF MULTIPLE-UNIT CAR

So far as multiple train operation is concerned, the physical structures of the road, such as station platforms, will more likely limit the ultimate length of trains than the train control apparatus. And when it is remembered that the adaptability of the multiple-unit control permits train operation in all classes of service, from street railways to steam road electrifications, one can readily understand, why the multiple-unit car is the ideal transportation unit for handling passenger traffic.

Single-Phase in Thirteen Years Successful Operation on the Erie

Q. W. HERSHEY

For the data and statements contained herein, the author acknowledges the assistance and approval of Mr. R. C. Thurston, Supervisor of Electric Service, by whom they were supplied.

ONE OF the principal northern feeders of the Erie Railroad system, with Rochester, N. Y., as the terminal city, makes connection with the main line at Corning, N. Y. At Avon, a point on this line eighteen miles south of Rochester, there radiate two additional intersecting lines, one west through LeRoy and Batavia to Buffalo, N. Y., and the other southerly through the Genessee Valley to Mount Morris, N. Y. This southern branch, from an operating standpoint, combines with the section from Rochester to Avon to form a straight north and south route line traversing the valley between Rochester and Mount Morris, a distance of 37 miles.

Prior to 1907 service was supplied between Rochester and Mount Morris and the villages lying between, chief of which are Avon and Geneseo, by infrequent steam service. The Genessee Valley is one of the famed beautiful, rich, agricultural valleys of the country with Mount Morris, an industrial town, at its head and Rochester at its foot on Lake Ontario. The activities of the valley were largely agricultural, along with those of a growing suburban residential district. Also various small industries were located in the villages enroute. The railroad service through these communities, between Rochester and Mount Morris, while fair, was not wholly satisfactory—a more up to date and desirable transportation service was looked forward to by these communities, particularly with respect to passenger and express conveniences.

A few years previous to this time the Niagara, Lockport & Ontario Power Company had built a transmission line eastward from Niagara Falls across the State of New York, following the cities lying adjacent to the route of the old Erie Canal, the terminus of this transmission line being Syracuse, N. Y. This transmission line crosses the line of the Erie Railroad some miles south of Rochester. This development, giving to the community the prospect of abundant and cheap electric power, lent impetus to the demand for a higher development of the transportation facilities of the valley.

With electric power readily available, and the success of electrified operation having been demonstrated at numerous other points over the country, the officials of the Erie Railroad were not tardy in perceiving the natural advantages which the transmission of Niagara power across their lines offered them as an instrument to be used in any proposed scheme of betterment of their service to the inhabitants of the Genessee Valley. Consequently, it was not a difficult decision with them as to what should be done in solving the problem of the improvement of their service. The decision to electrify a part of their system was made without hesitancy. It was determined that this improvement should be first applied to the thirty-seven mile section of road in the Genessee Valley, between Rochester and Mount Morris.

SYSTEM OF ELECTRIFICATION

The Niagara power transmission line carries three-phase, twenty-five cycle, 60 000 volt power. Successful railroad installations at other points had been carried out by the use of direct current on trolley wire or third rail, in somewhat similar service to that which the Erie proposed to apply to this district. At other points, such as on the New York, New Haven & Hartford Railroad, and the Boston & Maine, single-phase, 11 000-volt power on the trolley wire was in successful operation. At the time this installation was contemplated, had the direct-current system been selected, a very expensive system of power conversion by the use of power transformers and rotating converting apparatus would have been necessary, with the accompanying attendance expenses and costly feeder systems to give reasonable efficiency of delivery of power to all points along the trolley line, together with rather high power losses. After a careful study of this proposed installation, it was found that a single-phase electrification would require only a simple installation of two transformers, arranged to convert from three-phase, twenty-five cycles, sixty thousand volts to two-phase, eleven thousand volts, with a simple transformer station not requiring manual attendance. This station could be located near the center of the electrified section of the road, and the trolley wire arranged so that one phase would feed the northern end of the line, and the other phase the southern end. With the most simple type of single overhead trolley, of the catenary suspension type on wooden poles, and without any additional feeder other than the trolley and messenger wires, sufficient current would be available on any part of the line for any service which this community would need for many years to come, even though the traffic vastly increased. It was, therefore, decided that the single-phase system, with its attendant low power losses, high efficiency and reliability should be adopted.

THE EQUIPMENT INSTALLED IN THE ELECTRIFICATION

Much of the traffic originating in the terminus at Rochester goes through to Corning, the intersecting point of the main line. From Avon to Corning it is handled by steam. Traffic coming from the south and the west through to Rochester, would of course come by steam to the proposed electrified section at the Avon intersection. Some of the service from Rochester west to Buffalo runs through as full steam trains made up at Rochester, passing through the intersection at Avon. As it was desirable to maintain some of the service without the necessity of breaking trains and crews at the Avon intersection, the system of electrification should permit the use of both steam and electric service, the steam service being continued most largely in the through train service, both east and west, between Rochester and these points. It was desirable that the local passenger and express services between Rochester and Mount Morris be most improved. Accordingly, it was decided that the character of equipment best suited for this improvement would consist of motor passenger cars, motor express cars, and some combination passenger and express motor cars. Four passenger cars each seating fifty-six passengers and weighing 96 000 lbs., two combination passenger and express cars each weighing 96 000 lbs., one express car weighing 117 000 lbs., and one straight passenger car weighing 117 000 lbs., were selected and are now in service.

FIG. 1—SIX CAR TRAIN CROSSING THE GENESSEE RIVER

Enroute from Rochester to Avon on the electrified section of the Erie Railroad. This train [illegible] combination baggage and passenger motor cars in front, pulling one mail one express and two passenger [illegible] of as many as ten cars are sometimes operated.

No mountain grade considerations, in which electrification applies so favorably, were present to compel adoption here. The electrified section of the road is relatively a flat profile. The service was such that quadruple motor equipments of 100 hp admirably fulfilled all requirements. With each car equipped with four motors and multiple type control, not only could very excellent single car operation be provided, but there was sufficient margin of capacity in the motor equipment that train operation could be provided with all motor cars or with motor cars and trailers, using the motor car equipment as combination traffic vehicles and locomotives, as convenience and necessity demanded.

THE SUBSTATION

The substation to provide trolley current is of the most simple character. As the power is received three-phase, twenty-five cycle, 60 000 volts, and is to be changed to single-phase, twenty-five cycles, 11 000 volts, it is only necessary to have transformers with their switching and protective equipment. For the main conversion, two 750 kv-a transformers are used along with the usual lightning arrester equipment. The high tension switching is very simple, consisting of three fused, high-tension stick switches. While this form of switch was designed nearly twenty years ago, its use in this service has been most satisfactory. In fact, there never has been any trouble with it, and for operating conditions found here there would hardly seem any reason for substitution of the more complex and expensive oil circuit breakers. The low-tension switching has likewise been uniformly reliable and satisfactory. The substation operates without constant manual attention. It is given daily inspection, which consumes but a few minutes, but the successful operation is largely contributed to by the fact that there is a vigilant endeavor always to keep everything in fit condition. Contacts are kept properly trimmed up; oil clean and dry; joints, hinges, toggles, triggers, etc., well lubricated, and everything regularly cleaned. Attendance and maintenance costs of the station equipment are practically nil. There never have been any so-called station troubles.

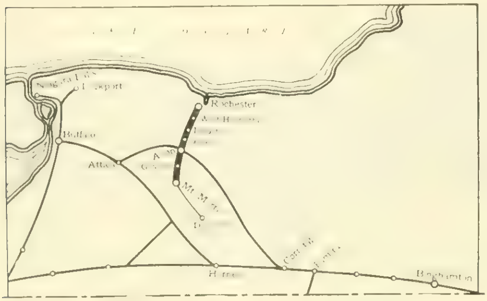


FIG. 2—ROCHESTER–MT. MORRIS ELECTRIFIED SECTION OF THE ERIE RAILROAD

The trolley construction was put up for use with the sliding pantagraph type of current collector. The overhead trolley was installed with wood pole construction and angle-iron side-bracket arms. The trolley is No. 3/0 hard drawn copper wire, hung 22 feet above the track from a 7/16 inch steel messenger, with hangers ten feet apart. The wood poles are spaced 120 feet apart. At the time this installation was made, overhead trolley construction was still somewhat in the experimental stage, particularly that of the catenary type of suspension. The hangers between the messenger and the trolley wire, were made up for rigid fastening at both the point attaching to the messenger and that attaching to the trolley wire. As a consequence, it was found that at certain points along the trolley wire this construction did not give sufficient flexibility to avoid hard spots and knocking. Consequently, crystallization took place at these points. To overcome this, about four years ago a supplementary solid steel wire was strung two inches beneath the trolley wire, with spacers alternating midway between the hangers supporting the trolley wire to the messenger. This was done for the purpose of giving additional flexibility, vertically, to the trolley wire rather than from any consideration of greater conductivity.

The supplementary steel wire has given perfect satisfaction in curing the fault for which it was installed, but experience indicates that the material in this wire should be something other than steel. Steel rusts very rapidly, which causes such rapid deterioration that the wire will probably have to be changed after approximately five years use. It has been suggested that phonoelectric wire or some similar material would eliminate this trouble.

Both rails are bonded with No. 3/0 compressed terminal bonds. Cross bonds are provided about every one-quarter mile.

OPERATION

A very material change in the frequency of passenger train service has been brought about through the institution of electrified operation. While occasionally some of the trains are run as single cars, it is a regular feature of operation that early morning trains out of Rochester are made up of two motored combination passenger and express cars used, as it were, as locomotives, hauling two mail and baggage coaches and two standard trailer passenger coaches. This particular six-car train runs through to the Avon intersecting point, where total steam service begins enroute to Corning. This early morning train is scheduled through to Corning, but certain cars later go on to Mount Morris. It is broken at Avon, the trailer passenger coaches going on to Corning as a steam train made up at this point. The motor coaches are later taken on to Mount Morris by another crew. It is a noteworthy feature, deserving particular attention, that the full train crew which brings the electric train from Rochester to Avon goes on to Corning. The electric motor crew steps off the electric motors onto the steam engine, which they take out from this point. The same holds true in the return operation later in the day, when the crew coming in from Corning to Avon on a steam engine change from the engine onto the electric motors by which they take the train on to the terminal at Rochester. Such operation, which has proved absolutely satisfactory, bespeaks great commendation for the simplicity and similarity of electric to steam control, as well as the better quality of enginemen talent.

From March 1, 1919 to March 1, 1920, a total of 312 539 motor miles were operated with 254 729 additional trailer miles. It is significant that during the past thirteen years of operation, no general tie-up of the railroad existed at any time from storm conditions, with the exception of one last year. At that time, the intersecting steam branches were tied up by snow for from ten hours to three days, while the electrified operation between Rochester and Mount Morris was delayed only four hours and, as stated, this was the first tie-up amounting to any hours during the whole history of the electrified operation of the road. With the ten cars in trailer service the monthly average maximum one-minute peak loads drawn from the power company equal something less than 1350 kw. The operation of the system, including station lighting, car heating, and repair shops, is carried on with a ton-mile power purchase of 79 watts.

RECORDS OF EQUIPMENT

All equipment is maintained and all work done, with the exception of machine work alone, which is done in the steam shop adjacent to the electric repair shop, with a force of five electricians, one laborer and one carpenter. The carpenter spends about one-fourth of his time on electric work and the other three-fourths on work in connection with steam equipment. This crew not only takes care of all maintenance of equipment and inspection, but in addition takes care of all line maintenance, as well as any work required in connection with substation maintenance. This maintenance force is paid standard steam classification rates. Inspection of motor equipment is made about every 800 miles, as cars normally come to the inspection house. Cars are operated in regular rotation to obtain a car about every three days. The operation of the motor equipment has been uniformly satisfactory. Most of the repairs are occasioned by burnouts from lightning or overloading, but these normally are of infrequent occurrence. The commutators average from 75 000 to 90 000 miles between turnings; gears around 300 000 miles; pinions around 150 000 miles; brushes around 10 000 miles; pantagraph shoes make about 10 000 miles between changes. The change required is merely that of replacing a plain one-eighth inch galvanized steel shoe without wearing strips; these cost at present about $2.50 each. The pantagraphs are lubricated with "used" gear grease about every 800 miles, when the cars come into the inspection shed. The pantagraphs have operated with uniform reliability. The total cost of power and maintenance of equipment, including the maintenance of overhead trolley and structures, averages about 10.4 cents per car-mile.

The shop capacity is for four cars. Except for light tools, the only facility required in the shop is a chain hoist. There are carried in the maintenance stock room, along with minor details of control, trolley, insulation, switch contacts, etc., four spare armatures and two spare fields. The total value of spare part material averages around $2500. There is one spare main transformer in the substation.

INTERESTING RESULTS

The system is exceedingly simple. It involves minimum costs on account of this simplicity, both as to first cost and that of operation, attendance, etc. Its operation has been thoroughly reliable and exceedingly satisfactory, not only to the railroad company but to the public served. This latter is recognized by frequent statements of the traveling public, when coming in from the steam intersecting trains, by their statements "We will go in over the electrified section on time". Others who commute to the City of Rochester have stated that, in all of the years in their travel on the Erie, they have never been late to work on account of the electric trains. It is significant, furthermore, that within one year after the opening of electrified operation, the traffic increased 100 percent over what had been the previous traffic under steam. The community's growth has been stimulated and likewise the community's traveling activities much increased.

[illegible]

References from the patrons to the desirability of living in the community are almost invariably supplemented by reference to the fact that the community between Rochester and Mount Morris has electrified service on the Erie Railroad. Taking it all in all, the engineers of the Erie Railroad are well satisfied with the reliability and satisfactory operation of the electrified section during the past thirteen years, as likewise are the officials, from the operating and income standpoint.

Multiple-Unit Control Equipments

For the Cleveland Interurban Railway Company

H. R. MEYER
Railway Equipment Engineering Dept.,
Westinghouse Electric & Mfg. Company

PERHAPS in no way are the unusual conditions now confronting the railway operating companies more clearly indicated than by the radical departure from customs adopted by The Cleveland Interurban Railway Company in mounting control apparatus. A careful analysis of the conditions surrounding the maintenance of equipment, first cost and reliability of operation, together with the multiple car operating features, was the basis on which the use of this type of control was determined.

THE CONTINUING success of the ordinary drum-type platform controller is due undoubtedly, to the unusual conditions under which railway companies are forced to operate. There is no question but that this type of control is enjoying a "comeback" possible only on account of the high cost of material, cost of installation and inability to obtain and keep the proper type of maintenance force.

It has become imperative with some companies to disregard the advantages to be gained with train operation where the platform controller is practically useless. This is due, not so much to an inherent inability to understand and realize the possibilities, but to the lack of funds to obtain them. As a consequence, a great number of operators who are blessed with "peak" traffic conditions are finding it difficult to provide the necessary equipment. In many cases, it has been necessary to resort to the use of trailer operation, where the leading car only is equipped with motive power. This form of operation has proven satisfactory where the motor cars have been originally designed for such service. However, a large percentage of trailer operation is obtained at the detriment of the equipment on the motor car. It is possible that these equipments are just about capable of handling the service, but any unusual condition, such as the cutting out of a motor or a pair of motors, overloads the remaining motors to such an extent that the two cars must be cut out of service or a burned-out motor may be the result. Of course, the cutting out of a motor, or a pair of motors, is the exception rather than the rule; but where equipments are worked up to the maximum capacity, it is not so frequently the exception.

The importance of the operation of trains during rush-hours is clearly illustrated by the schemes employed by various operating companies to obtain it. However, on analysis, all of these schemes, have been worked out with the idea of securing the combination of equipments which will give the desired result with a minimum expenditure of money. For this reason, the platform controller has been considered from all angles as one means of obtaining the simplest type of train control, using motors on all cars. Two schemes using this type of controller have been tried out with partial success, but the indications do not point to a widespread use of this form of control. In one of these two systems, two slightly different platform controllers are used with power wires carried between the cars. The other system employs a separate remote-controlled magnetically-operated reverser, having both control and power circuits carried between cars.

FIGS. 1 AND 2—END AND SIDE VIEWS OF CAR ON WHICH EQUIPMENT IS MOUNTED

With both of these schemes of control, only two cars have been operated in train commercially, up to the present time. This is primarily due to inherent complications in the power circuits between cars. One of the main disadvantages of this form of control is found in connection with the coupling of cars. The power circuit connections between cars are cumbersome, and the trailing motor car must always be connected with a leading motor car. If either of the above-mentioned systems is used, coupling of cars into trains is limited to definite units.

All attempts to obtain a control for train operation, based on modifications of the platform controller, have been caused by the relatively higher cost of the present standard forms of multiple-unit control. The Cleveland Interurban Railways Company, however, not being satisfied with the showing made by various freak equipments, and being forced to go further by future service demands of three or more cars in a train, made a complete study of the whole situation. Various methods of apparatus mounting were considered along with the types of detail apparatus available. Plans were made up showing these mountings with an analysis of the total costs involved. It was found that, by mounting practically all of the apparatus on the platform of the car in a specially constructed case, a control could be built whose cost would not greatly exceed that of the modified platform controller. This type of control would also retain all of the advantages of the standard multiple-unit control. In fact, as far as the operation is concerned, it is exactly the same as the standard.

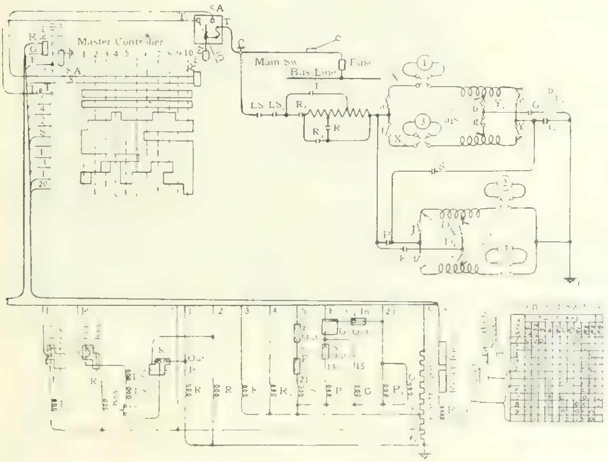


FIG. 3—MAIN AND CONTROL CIRCUIT SCHEMATIC DIAGRAM.

Cut-out switches *a, b, c, d* and *e* are connected to *No. 1* handle. Cut-out switches *f, g, h, j* and *k* are connected to *No. 2* handle. Leads A, A_1, B, B_1, C, C_1, D and D_1 must have the same resistance.

The cars on which this control is used, as shown in Figs. 1 and 2 are of the center-entrance low-floor type. Operation is single-end, with the platform shut off from the passenger compartment by a bulkhead placed diagonally to give increased space for the control cabinet. The motive power consists of four 50 hp, field-tapped, outside hung motors. Their operation is made especially quiet by the use of helical gears.

All of the main parts of the control, except the line switch, control resistor and main grid resistance, are mounted on a structural steel frame which, in turn, is fastened to steel supports by insulated bolts. The line switch, control resistor and grid resistor are mounted underneath the car floor. The frame work, with the control apparatus mounted thereon, is enclosed by a wood cabinet finished to match the rest of the woodwork of the car proper. The cabinet or control housing is mounted on the platform of the car on the left-hand side. It extends from the floor to the canopy and, although not arranged so now, can be ventilated through the roof for the escape of gases caused by the opening of the unit switches. One of the most important considerations in the selection of the types of equipment to be adopted, outside of the space factor, was that of maintenance. With the exception of the line switches, grid resistor and the control resistor, all apparatus is inspected and repaired under exceptionally comfortable conditions from the workman's view point, as all parts of the apparatus in the cabinet are accessible to the inspectors while standing or sitting in a normal position. As a result, the work is done very efficiently as regards thoroughness and speed. All minor repairs can be made under exceptional working conditions and, as the whole is made up of unit parts each of which can be quickly and easily removed, spare units can readily be installed while bench work is being done on damaged units.

The system of control used is of the electropneumatic unit-switch type, wherein individual unit switches (each complete in itself) are used to obtain the various notches. The method of operation of this control, together with the motors used, indicates the source of the name applied, that is, "HLF" which means, acceleration is obtained by hand notching, power for the control is obtained from the line and the motors have field taps. Five notches in series and five notches in parallel are used. The short field connection is obtained only on the last parallel position.

DIAGRAM OF CONNECTIONS

The scheme of main circuit connections is shown in Fig. 3. With these connections, a minimum number of switches are required to obtain tapped field operation of the motors. The sequence in which the switches are operated, and, hence, the method of securing the various notches, is indicated in Fig. 3.

[illegible]

CAR WIRING

The arrangement of connections to the apparatus, including the motors, is similar to any other multiple-unit control, except that the main circuits to the field taps and the end of the field have permanent connections. With the field connections indicated in Fig. 3, it has been found advisable to take precautions, in connecting the field taps for the short field connection, so that the wrong section of the field will not be used. It has also been found necessary to make equal the resistance of the interconnections between the motors connected together. This can be accomplished by using cables of the same length and size, or different size cables of different lengths, but the same resistance. Leads, which should have the same resistance, are indicated in Fig. 3.

As these equipments are single-end, only one control junction box is used. This junction box is placed on the floor of the car in the bottom of the control cabinet. Connections to the master controller train line, which extends the length of the car and terminates in intercar connectors, and the control rack, are made directly from the control junction box.

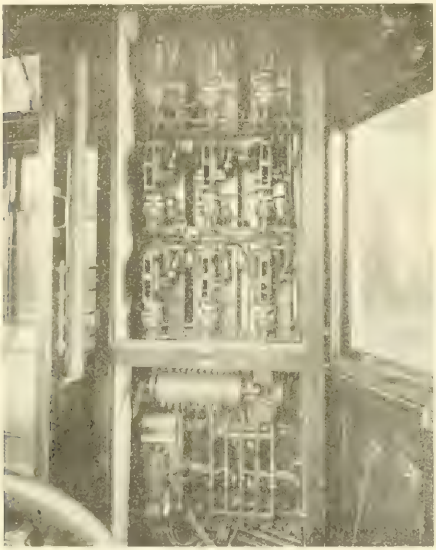


FIG. 5—CONTROL RACK FOR APPARATUS MOUNTED IN CABINET.

AIR CONNECTIONS

Compressed air is taken directly from the main reservoir through a cutout cock, strainer and check valve to the control reservoir. From the control reservoir, connections are made to the various pieces of apparatus on the control rack, with pipe insulators interposed between the various pieces of apparatus. An extra cutout cock is placed in the bottom of the control cabinet for inspection purposes. Connections between the individual switches are accomplished by means of a coiled copper tube and gasoline pipe-line connectors. The arrangement is such that any unit can easily be removed for repair or replacement.

CONTROL CABINET

The housing for the control apparatus consists of a wood box frame, open at the back, front and sides. All sides of the box frame are fitted with two removable doors, one at the top and the other at the bottom. This arrangement facilitates inspection of the apparatus from all angles and simplifies repair work. The inside surfaces of the box frame and all doors are lined with one-fourth inch asbestos lumber, for fire-proofing. The cabinet is left open at the bottom, as it rests directly on the floor. It is located on the left-hand side of the operating platform, as shown in Fig. 4. Access to the back of the cabinet is obtained by removing a window, which is specially constructed for that purpose.

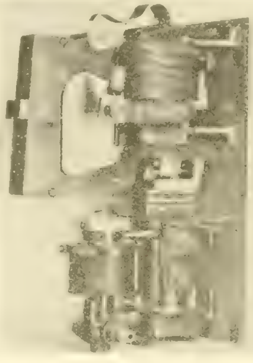


FIG. 6—ELECTROPNEUMATIC UNIT SWITCH
Mounted in cabinet.

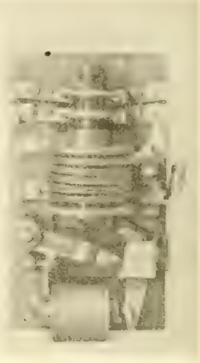


FIG. 7—OVERLOAD TRIP
Mounted in cabinet.

CONTROL RACK

On a structural steel frame, intended for mounting in the vertical position, are mounted the unit switches, reverser, overload trip and the motor cutout switches. The grouping of the apparatus and the position of each individual piece is shown in Fig. 5. The top of the frame is supported by a bracket fastened to the cabinet. The frame is fastened to the support by two horizontal, insulated bolts. The bottom of the frame is supported by a bracket mounted on the floor in the cabinet. The insulated bolts used to fasten the frame to the bracket are placed in a vertical position so that

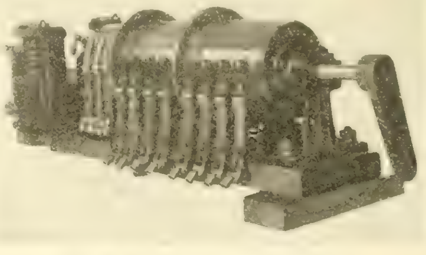


FIG. 8—ELECTROPNEUMATIC REVERSER
Mounted in cabinet.

the weight of the outfit is supported by the insulators and not by the bolt. As the frame or rack is insulated from the car body, and as each piece of apparatus is insulated from the frame, the apparatus has double insulation to ground.

UNIT SWITCHES

Each unit switch is complete in itself, ready for mounting in position. It consists of three essential elements,—the switch mechanism, the cylinder and valve magnet details for operating the switch mechanism, and the blowout coils and arc chutes to take care of the expulsion and confinement of the arc. As shown in Fig. 5, a vertically mounted insulated base supports the cast structure comprising the magnetic circuit which, in turn, supports the arc chute. The blowout coils are wound on the cast structure. A cast brass bracket, also mounted on the insulated base, carries the top contact forming the stationary jaw of the switch. The moving part of the switch, carrying the lower contact or moving jaw, is mounted on the piston insulator connected directly to the piston rod of the operating cylinder assembly. The cylinder assembly, with magnet valve, is attached to the same insulating base as the other details enumerated. This construction gives a very compact, light, rugged and efficient switch.

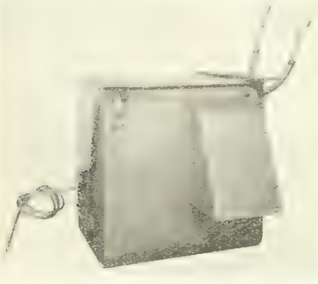


FIG. 9—ELECTROPNEUMATIC LINE SWITCH
Mounted underneath car floor.

The arrangement of operating cylinder and piston is such that the full pressure of the piston, minus the pressure of the retrieving spring, is obtained at the switch jaws. With a reservoir pressure of 70 pounds and a piston area of 3.06 square inches, a total pressure of 214 pounds is applied at the piston. As the retrieving spring has a pressure of approximately 65 pounds in its maximum position, the pressure at the switch jaws is 150 pounds. When the reservoir pressure falls as low as 50 pounds, there is still a pressure at the switch jaws of approximately 90 pounds. This pressure at the switch jaws assures a good contact at all times, being unaffected by drop in line voltage.

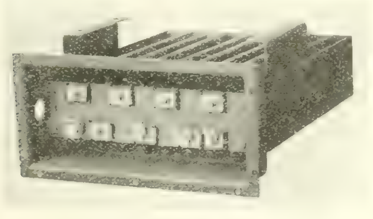


FIG. 10—CONTROL RESISTOR
Mounted underneath car floor.

OVERLOAD TRIPS

To protect the equipment against overloads and short-circuits, a series coil overload relay is employed. This relay, Fig. 7, has a series coil connected directly in the trolley circuit. The coil is form-wound, supported by a hollow soft steel core, supported by a three-quarter soft steel yoke. Within the hollow core is a plunger rod, to the top end of which are fastened two flexibly supported contact discs. These discs, when the plunger is in the down position, make contact with fingers arranged at the sides of the discs. Attached to the lower end of the yoke is a trip lever, forming the fourth quarter of the yoke which, when an overload or a short-circuit occurs, is attracted to the hollow core. Before the lever touches the core, it comes in contact with the plunger which it lifts, disengaging the contact discs from the fingers, thereby opening the connections between the discs and the fingers. This lever is held in the trip position by a latch. After the overload trip has operated, it is reset by throwing the handle of the control and reset switch to the reset position, whereby the reset coil circuit is energized, releasing the lever from the latch.

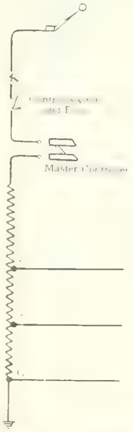


FIG. 11—SCHEMATIC DIAGRAM OF CONTROL RESISTOR

REVERSER

To change the direction of running, a small electropneumatic reverser is used. This reverser was designed for economy of space and weight, with especial attention to insulation between contact positions. The general assembly is quite similar to other reversers, except that it is built in skeleton form. Fig. 8 shows the details of construction.

As the fields of the motor are of the tapped variety, the armatures of the motors are reversed rather than the fields. This arrangement has been used to reduce the total number of unit switches required. The complete reverser weighs but 35 pounds.

CUTOUT SWITCHES

Ten single-pole single-throw switches are arranged in two combinations of five blades each. Both combinations are mounted on an insulated base with the hinge jaws connected together. One combination cuts out one pair of motors and the other combination cuts out the other pair.

APPARATUS MOUNTED UNDERNEATH THE CAR FLOOR

Line Switches—As an additional protection to the equipment, a two-unit line switch is mounted underneath the car floor on the operating end of the car. The switches used in this line switch are the same as the units mounted in the control cabinet, so that all parts are interchangeable. These two switches, however, are enclosed in a sheet metal, weather-proof case. The particular advantage of this external line switch is found in connection with the handling of short-circuits and heavy overloads. An external view of this line switch is shown in Fig. 9.

Control Resistor—All control circuits are energized at a relatively low voltage. As the energy is obtained from the trolley, it is necessary to use some reducing medium. The simplest and cheapest method of obtaining the required voltage is by means of a resistor properly designed to give the best average top voltage over a wide range of conditions. The resistor shown in Fig. 10 is known as a heater type, as the insulation is entirely of mica and is sufficient to withstand a test of 3500 volts alternating-current for one minute. In Fig. 11 is shown, schematically, the arrangement of taps to obtain the required voltage.

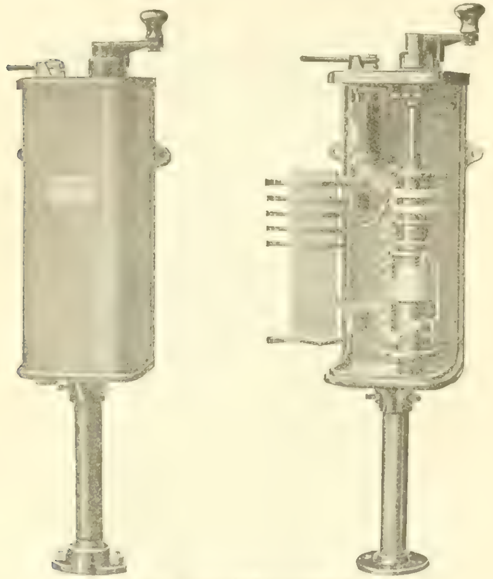


FIG. 10—CONTROL RESISTOR

The Grid Resistor consists of four frames, each made up of 25 cast-iron grids. All notches are designed to give smooth acceleration under average conditions. Liberal capacity allowances, consistent with minimum weight and space factors, are used.

OTHER DETAILS

Canopy Switch—In addition to the other main circuit apparatus enumerated above, a switch is placed in the trolley circuit ahead of all other apparatus except the fuse, which is mounted on the roof. It is a car-type circuit breaker with the trip removed. For emergency cases, the operator can easily reach the handle of this switch, as it is mounted directly above his head.

Master Controller—Only one master controller is used, as the equipments are for single-end operation. It is of the usual type employed with multiple-unit control equipments. Primarily it comprises two drums, mounted on separate shafts, but so interlocked that the operation of one is dependent on the other. The first or main operating drum has a high and low-voltage section. The high-voltage section makes and breaks the connection between the trolley and the control resistor. The low-voltage section controls the operation of the individual switches. The second or reverse drum controls the direction of running. The control resistor is connected directly across the line every time the master controller is thrown to the first notch, and when the master controller is thrown to the off position, the resistor circuit is broken. A view of the controller is shown in Fig. 12.

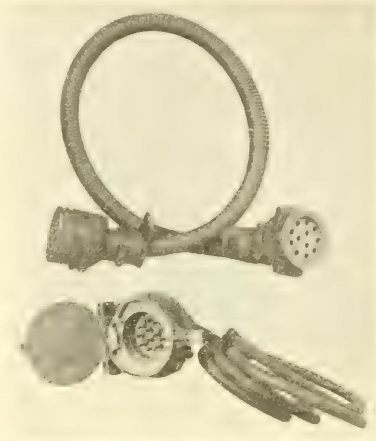


FIG. 13—TRAIN LINE RECEPTACLE AND JUMPER

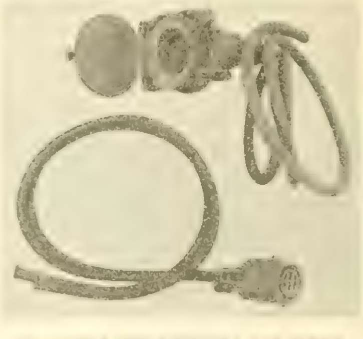


FIG. 14—BUS LINE RECEPTACLE AND JUMPER

Train Line Receptacles and Jumpers—The train line, which extends the entire length of the car, and which is connected directly to the control circuit through the control junction box, terminates at each end of the car in a train line receptacle. Connection of the train line circuit between cars is accomplished by means of these receptacles, Fig. 13, and a jumper equipped with plugs which fit into the receptacles. A unique method of preventing the jumper-head from pulling out in service is obtained by means of a locking ring, which holds the jumper-head securely in place.

Bus Line Receptacle and Jumpers—Extra heavy duty bus line receptacles and jumper are used. They are capable of handling sufficient power for a four-car train with the trolley up on the first car only. Both the train and the bus line receptacles are mounted on the drawbar. Fig. 14 shows the general appearance of the bus line receptacles.

A number of these equipments have been operating since April, 1920. The operation has been eminently successful. The cars have been operated mostly as single units, except for trains used to make tests. As the traffic becomes heavier, it is intended to run two or more cars in a train rather than change the headway of the cars.

The Maintenance of Railway Equipment

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IN CERTAIN respects the railway motor is very much like a human being. The best results are, as a rule, obtained when it is working under a normal load and under favorable working conditions. Either can withstand a reasonable overload at intervals without noticeable injury provided it is of short duration. Neither can successfully stand continuous overload without breakdown. Neither can stand much of an overload, even for a short time, if in a badly run down condition. The success of an individual is in a very large measure the result of a happy combination of personal characteristics, suitable occupation and intelligent care of the physical and nervous system. Likewise the successful performance of the railway motor is the result of three factors, or rather three groups of factors, namely:—1—good design, workmanship and material; 2—proper application and operation; 3—intelligent care and maintenance. When one of these factors is missing there will certainly be a lower efficiency, a lower effort and a lower accomplishment. Of these factors, as bearing on the performance of railway motors, the last mentioned, namely, care and maintenance, is unquestionably the most important.

While there is a wealth of theory and data that demonstrates the truth of the above statements, cold figures are often not entirely convincing. A striking proof, however, is furnished by the experiences of many properties in the Middle and Atlantic States last winter. Some properties suffered an absolute tie-up of traffic because of extraordinary storms. Much of this probably could not have been averted, except by the fullest preparation and organization of snow fighting equipment and forces. There were, however, a few conspicuous properties which came through the severest storms with only slight casualties, when all around them there was a general breakdown in service. Very fortunately, the answer to this was simply that these particular properties had overhauled their equipment the summer and fall previous, and had put everything in first class shape. The motors entered the severe winter with the insulation in good condition, so that it kept out the moisture and dust and prevented short-circuiting the turns in the coils. The individual wires had insulation with life in it instead of partially charred material separating them from each other. Even slightly charred insulation is a direct invitation to leakage and short-circuits under conditions of overload or excessive moisture. Leaky insulation is like a leaky roof; its action is insidious. It has a deceptive way of seeming to be all right in fair weather. A little moisture starts a very slight leakage of current. A slight charring of the insulation follows which increases the leakage of current. Thus the trouble pyramids at a high rate and, with a bad rain or snow storm, the end comes quickly and decisively. There is a short-circuit or a ground and the car goes to the barn. The worst part of this is that the car is laid up at a time when it is most needed—when the elements are all combining to cripple the service. The time for that car to have been in the barn was in the early fall or summer when it could have been much more readily spared for overhaul of the equipment.

The "stitch in time" philosophy is old almost as time itself. It is a trouble saver in very many phases of life. But nowhere has it a more important application than in railway equipment. This is because the operation of street cars is essential under emergency conditions. In the northern sections emergencies come in the winter or spring, and there is no way of predicting in the fall what the coming winter will be like. Neither the height of the wasp-nest above the ground nor the extent of the squirrel's stores can be relied upon as an indication of what the railway equipment will have to go through during the coming winter. There were many who felt that the winter of 1917-18 was so severe that it was not likely to be duplicated for many years to come. Yet the winter of 1919-20 surpassed that one in severity, in many localities. It is clear then that it is never safe for the railway manager to discount the coming winter and slacken up on his maintenance of equipment.

It is further evident that maintenance must be on a systematic basis. There is no lack of methods of keeping track of the various parts of equipment, its troubles, maintenance, overhaul, etc. The great lack in many instances is a thorough appreciation of the need of system. Wrong conclusions as to the cause of the trouble are the logical result of insufficient analysis. Correct analysis can only be made with the entire truth before us. Half truths are at the bottom of much expensive trouble. A striking example of this occurred in connection with armature trouble which was reported on a certain type of motor. A winding expert was called in to investigate. The case was mysterious from the beginning, as the epidemic began very suddenly and without any apparent cause. A systematic checking up finally disclosed the rather startling fact that four of the armatures had failed in one particular frame. This frame had been put on a different car each time a new armature was put in, and had thus avoided detection. The offending frame was located and it was found to have a main field coil reversed. Correction of the field was made and the epidemic of armature trouble stopped immediately. It required considerable detective work to run this down, all of which would have been saved by a systematic checking up and inspection of the first failure. Even had this been neglected, the trouble would still have been caught at the second armature failure had there been a complete identification and record of the first failure. Probably, a study of this record would have placed suspicion on this frame. The particular system of records to be used will vary with conditions, localities and personal characteristics of those in charge, but the need of some form of reliable records is common to all and is the thing that needs to be emphasized most at the present time.

The conditions under which maintenance is carried on have an important bearing on the results obtained. Good work in inspection, repairs and overhaul of equipment cannot be expected when overhauling pits and other facilities are not in good shape. No pitman can do good work with poor light or with tools that are worn out. Defective extension light cords are a frequent source of annoyance and delay. On a certain occasion, the writer was deeply impressed by the loss of time and efficiency because a pitman required 35 minutes to find material and make repair to an extension cord. Considering that the pitman's useful time was from midnight to 4 o'clock A. M. this 35 minutes meant about 15 percent of his total time for that night, spent on work strictly outside his regular duties of inspection.

The pits should be kept reasonably warm in the winter. No one can do maintenance work properly in a temperature which benumbs the hands. The quality of work is poor because the morale or spirit of the men is poor. It cannot be otherwise under bad conditions.

The pitman is often condemned for faults that crop out in the equipment for which he is really not to blame. He is sometimes accused of not keeping axle cap bolts tight, for example, when the real fault lies higher up and is traced to defective or worn out wrenches with which he is supplied. While investigating maintenance conditions, the writer has frequently been impressed with the spirit of co-operation which prevails among these men as a class. They give and receive suggestions in fine spirit. This spirit is an important factor in building up an efficient maintenance organization. We all know that willingness to learn, to co-operate and to put the shoulder to the wheel are far more valuable than knowledge in itself. The writer is of the firm conviction that one way of improving the work of the pitman is to furnish him with the proper facilities for handling his work. This is bound to raise the quality of his work.

Experience is a harsh and expensive teacher, but there is none more reliable, none which drives the lesson home with more force. There have been many lessons in the experience of the last few winters, but these lessons are not new. In some instances, however, the pupils are new. Perhaps they have to have a real taste of trouble before they get the relative values of things fixed in their minds. Unless sometime you skate near the edge, you do not know just where the edge is, and are liable to fall in when least expecting to do so.

The troubles that occurred last winter amounted almost to a catastrophe in some communities. When reviewed close at hand, only the appalling effects of this are in evidence. Frequently afterwards, there arises a better structure or a better organization which will prevent a similar catastrophe in the future. There are numerous hopeful signs which indicate that profit is now being taken from the big investment in experience in the recent severe winters—signs of a lively appreciation of the value of introducing scientific methods into maintenance, systematic study of troubles, foresight in preparing for the rainy day. The manufacturers' engineers, the operating engineers, and the master mechanics are getting together more than ever before to work out a solution to maintenance problems and improvements in designs. These are only a few of the hopeful signs for the future of the electric railway.

Electric Braking of Direct-Current Vehicles

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THE VARIOUS terms used in electric or dynamic braking, as well as the field of application of the braking schemes in common use, are often confused. The following gives a brief resume of the fundamental principles involved.

The term electric or dynamic braking is properly a general one, and refers to the braking effect secured by converting the propelling motors to series generators, driven by the momentum of the vehicle. Rheostatic braking, magnetic braking, and emergency dynamic braking are specific terms referring to the method of absorbing or applying this dynamic energy.

More specifically, in rheostatic braking the energy is absorbed by a resistance which is varied as the car speed is reduced. In magnetic braking, magnetically-operated track brakes are inserted in the circuit with an adjustable resistance for varying the braking effect as the car speed decreases. Emergency dynamic braking refers to the dynamic braking effect secured in an emergency by reversing the car, when the momentum of the car drives the motors as generators connected two in series on short-circuit.

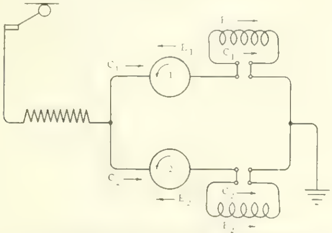

FIG. 1—NORMAL RUNNING CONNECTIONS

RHEOSTATIC BRAKING

Figs. 1 and 2 illustrate the method used to secure rheostatic braking. For simplicity a two-motor equipment is shown. The arrows indicate the direction of armature rotation, current flow, armature voltage and the field produced by the main field coils. The armature voltage *E* is the counter electromotive-force of the machine when acting as a motor, and its generated voltage when acting as a generator. The field *F* is produced by the current flowing in the main field coils or the residual field when no current is flowing. C_1 and C_2 represent the current in each machine, and *c* indicates the circulating current which tends to flow under certain conditions described below.

Fig. 1 shows the conditions which exist during normal running. Fig. 2 shows the conditions which exist in the braking position. It will be noted that the fields of the two motors have been interchanged as well as reversed. If the fields were simply interchanged without also being reversed, or if they were reversed without being interchanged, emergency dynamic braking only would occur, just as though no resistance were connected across the motor terminals. If the fields were neither reversed nor interchanged, the current through the field would be in such a direction as to demagnetize the field producing it and the motors would fail to build up as generators.

This scheme also insures equal voltages on the two machines and stability of the system, any unbalancing of the load which might tend to occur due to slightly different characteristics of the two machines being automatically compensated for. For example, assume that No. 1 motor generates a higher voltage than No. 2. The tendency will then be for the former to circulate a current *c*, through No. 2 machine in a direction opposite to the voltage which it tends to generate. This current, however, will be in such a direction as to oppose the main field current in No. 1 machine, reducing the flux and therefore the voltage, and will also be in such a direction as to strengthen the main field current in No. 2 machine, raising its voltage. In other words, the voltage of No. 1 machine will be decreased at the same time the voltage of No. 2 machine is increased until the two voltages are exactly balanced and no circulating current will flow. Both machines operating in parallel will assume their share of the external load.

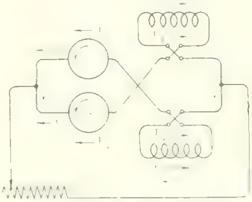

FIG. 2—[illegible]

As the speed of the car decreases, the resistance is gradually cut out of circuit by the controller. As the braking effect depends upon the power generated, which in turn decreases as the car speed decreases, it is necessary to provide an auxiliary braking system to bring the car to a final stop or hold it on a grade.

In equipments provided with rheostatic braking, it is necessary to provide for increased motor capacity, and this fact, together with the added complication of the control circuits and the wide use of the air brake, has resulted in the practical abandonment of this scheme of control in this country, except for special applications, such as mine locomotives, where the space requirements may not permit the installation of air brake equipments.

MAGNETIC BRAKING

When the external resistance is replaced by the magnet coils of track brakes which act on the track and wheels, effective braking is obtained with much less current through the motors than with rheostatic braking. Under these conditions, it is customary to employ the scheme of connections shown in Fig. 3. The connections in motoring are the same as shown in Fig. 1. In changing from motoring to braking the motor fields are reversed as in rheostatic braking, but in place of interchanging the fields, a connection is made between the two motors, as shown. While this method of connection has the advantage of slightly greater simplicity in control, and is satisfactory with the low currents usually required for the operation of track brakes, it cannot be used in rheostatic braking, where the current handled is of considerable value, due to the unbalancing in load which may be obtained with this scheme of connections.

For example, referring to Fig. 3, if we again assume that the characteristics of No. 1 machine are such that it will generate a higher voltage than No. 2, it will tend to circulate a current *c* through No. 2 armature, increasing the internal voltage drop in No. 1 machine until the terminal voltages are equal. This may result in as high as 100 percent unbalancing, or more. The tendency toward unbalancing may be lessened by inserting resistance in the equalizing connection.

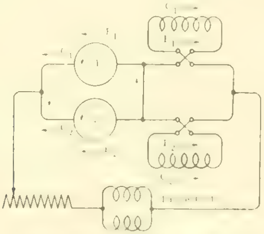
FIG. 3—MAGNETIC BRAKING

In order to limit the amount of current through the track brake coils to prevent slipping of the wheels, it is common practice to provide a regulating resistance which, in connection with a regulating relay, shunts a portion of the field current when the braking current reaches an excessive value. Figs. 4 and 5 indicate the scheme of connections used. Resistance is also inserted in the connection between the two machines in order to decrease any tendency toward unbalancing. In some cases it has also been found necessary to use a demagnetizing shunt, which serves to release the track brakes when power is again applied in the forward direction.

Although magnetic braking is used quite extensively in Europe, it has been practically abandoned in this country. This is largely due to the following reasons:

1—The large amount of special work, such as frogs, switches, street railway crossings and steam railroad crossings is a big handicap to the magnetic brake, as they tend to produce high maintenance on both the magnetic brake shoe and the track.

2—In order to obtain an effective magnetic brake, it is necessary to design the truck especially for this feature, which involves additional cost, often increases the length of wheel base and usually results in a special type of truck for almost every new equipment.

3—In the past, the application of magnetic brakes on cars operated in America has resulted in the development of many detail designs, caused by the differences in schedule, in car construction, in truck construction, in rail construction, in size and characteristics of motors, and in desires of the local operator.

EMERGENCY DYNAMIC BRAKING

In any railway motor equipment, except where only one motor or its equivalent of two connected permanently in series is employed, it is possible to secure an emergency dynamic braking effect by the proper manipulation of the controller. With a four motor equipment, where the motors are connected permanently in parallel pairs, it is only necessary to reverse the fields of these motors with respect to their armatures by throwing the reverse lever. On a two-motor equipment it is also necessary to move the controller handle to the first parallel position. In such a case, as stated above, the momentum of the car will cause the motors to be driven as generators, connected two in series on short-circuit, and the car will be retarded by the heavy dynamic current which tends to flow in such a case. The various principles involved and the successive actions produced have been fully described in a previous issue.* The effect produced is very severe, it cannot be regulated and should be regarded as an emergency measure to be used only in an extreme case, when all other means of stopping the car have failed.

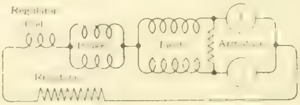

FIG. 4—MAGNETIC BRAKING BEFORE REGULATOR LIFTS

In certain types of equipment, the application of this emergency feature is not always under the control of the motorman, such as upon loss of trolley voltage in remote control equipments operated by the line current. Under such conditions some operators provide a means by which the reverser can be thrown by hand in emergency.

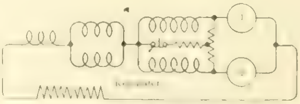
FIG. 5—MAGNETIC BRAKING AFTER REGULATOR LIFTS

There are certain fundamental principles to be observed in the application of such a scheme, as follows:

1—It must be operative in the event of loss of power.

2—It must be operative in the event of loss of air in any system where the control elements are normally operated by air.

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*See article on "Emergency Braking" by J. A. Clarke, Jr., in the JOURNAL for Oct., 1916.

3—Once established, it must be inoperative until the vehicle has come to a standstill, in order that it will perform its functions automatically in spite of any interferences due to change of mind or loss of head by the operator.

4—In case of the vehicle stopping on a grade, it must be established in the reverse direction to normal to prevent the vehicle from rolling backward down hill.

5—It must not be so convenient as to encourage abuse, yet it must be instantly available in case of emergency.

6—It should be easily inspected to insure that it will always be in working order.

There are various schemes for securing emergency braking which have been proposed or are at present in operation, none of which, however, incorporate all of the above principles. In the selection of any scheme, local conditions and the exact result desired will determine the best arrangement to be used.

Effect of Short-Time Overloads on Railway Motor Armatures

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THE WINTER of 1917-18 and the past winter were severe ones from the standpoint of the railway operating man. The average line had to strain its energies to the utmost to keep the equipments in running condition. One of the most frequent forms of motor failure was roasting armatures. The causes of these roasted armatures were sometimes easily understood, but were often not so obvious, due chiefly to a lack of appreciation of the effects of short-time overloads on armature insulation.

The apparent temperature, as measured on the outside of the coil of a railway motor by thermometer will be lower than the actual copper temperature due to the drop through the insulation. The A. I. E. E. rules provide for a correction of 15 degrees to be added to the apparent temperature. In the average case this will give results fairly close to the actual copper temperature. In the discussion below the temperatures referred to are actual copper temperatures.

The class of insulation used in railway motor armatures has a long life, if subjected to temperatures that never exceed 105 degrees C. This insulation also has a comparatively long life even at ultimate temperatures as high as 115 degrees C. At temperatures materially higher than 115 degrees C. the life is greatly reduced. Temperatures of 125 degrees will ruin the insulation in a few weeks, if maintained steadily. Temperatures as high as 160 degrees will destroy the insulation mechanically in a very short time. On low voltage, the insulation may still be satisfactory from an insulating standpoint, but in railway service especially, it will soon flake off, powder, crack or be crushed by the mechanical action of the coils, allowing the conductors to make contact with each other or with ground, resulting in an armature failure. It will often take several days or weeks after the overload for this failure to occur, thus hiding the actual cause of the trouble. When the insulation has once been roasted, moisture or another overload may break down the insulation altogether and failure will occur.

As a general rule, the current density is higher in the armature copper than in the fields of a railway motor. Due to the distributed winding, the better ventilation and the larger mass of iron immediately adjacent to the coils this higher density is permissible. Under ordinary running conditions, it does not result in temperatures any higher than those in the field coils.

The copper loss of the average ventilated railway motor is from 60 to 80 percent of the total loss at the hour rating, while the copper weight is only 10 to 15 percent of the total motor weight. This means that the bulk of the heat generated in the copper must be transferred to the iron or the cooling air. Otherwise, the temperature rise in the copper will be excessive. The magnitude of this heat transfer may be judged from the curves in Fig. 1, which give watts loss per pound of armature copper for various percentages of the hour rating for typical railway motors. It is known that a loss of five watts per pound of copper (equivalent to 1390 amperes per square inch of current density) for one hour will raise the temperature of the copper 100 degrees C. if there is no heat transfer. These curves show a loss at the hour rating of 17 to 60 watts per pound of copper. Obviously there is a large amount of heat transfer in the armature windings of these motors at this rating, for the actual copper temperatures do not exceed normal values. These curves also show how the allowable loss per pound for a given temperature rise decreases as the motor size increases, due to the smaller radiation surface of the copper per pound, and the increased eddy current losses.

The effect of a short, heavy overload is to give an entirely different temperature distribution than is obtained under rated load conditions. If instead of the rated current, three times this value be applied, the armature copper losses will be increased nine times, but the time to reach dangerous temperatures is much shorter than might be expected. The temperature reached is no longer a question of storage capacity and radiation of the armature as a whole, but of the heat absorbing capacity of the copper in the slots. Since the copper mass is so small, it can absorb the heat generated only by a great increase in temperature. The temperature reached is a function of insulation thickness, current density, insulation material and slot shape. It is not materially affected by the heat storage capacity of the armature iron under these conditions.

Tests show that when three times rated current is applied to the average railway motor, the armature copper will rise 40 to 60 degrees C. above the iron in one minute, depending upon the motor rating. There is a difference of only 20 or 25 degrees between iron and copper on the continuous or even the hour rating. This means that the heat is concentrated in the armature copper during short overloads and soon destroys the insulation. The field coil temperatures under these loads are not so high, because of the greater copper mass and the lower densities at which the fields are worked. This emphasizes another point shown in Fig. 1, namely that the temperatures reached on short overloads are lower in the large motors than in the small ones. The smaller radiating surface per pound of copper and the larger eddy current loss in the larger motors necessitate lower current densities and hence lower losses per pound of copper. This means that the larger motor inherently has a larger overload capacity than the small one. For example, a motor rated at 60 amperes will stand 180 amperes for two minutes with a rise for the armature copper of 100 degrees C. above the iron, while a motor rated at 200 amperes will stand 600 amperes for nearly four minutes with the same rise.

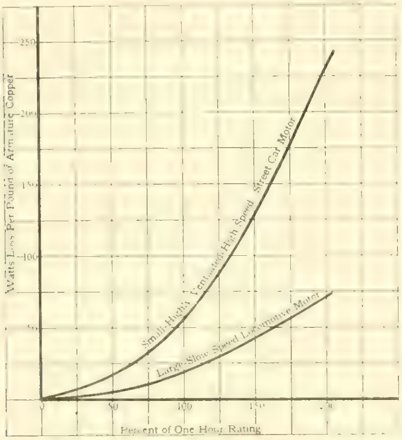

FIG. 1—WATTS LOSS OF RAILWAY ARMATURES AT VARIOUS LOADS

Numerous tests have been made to determine the effect of a cycle of operations on motor temperatures. The curves shown in Fig. 2 are the result of such a test. The motor under test on the lower curve was run for four hours totally enclosed at its continuous rating of 31 amperes, then 100 amperes were applied for one-half hour. The resultant temperatures shown in the curve were thermometer readings of field coil temperatures. The armature copper temperatures were undoubtedly much higher. The temperature rise of the field coil was doubled in the first ten minutes of the 100 ampere load. The upper curve is for a ventilated motor with the same continuous rating as the non-ventilated motor. It shows the same results except that they are much exaggerated. The heat storage capacity of the second motor is much less than that of the first, and the temperature on overload is correspondingly higher. To save the motor it was necessary to shut down after ten minutes of overload. The probable temperature, if the load had been continued, is shown by the dotted line. This gives an idea of what may be expected if a short heavy overload is put on a motor after operating it for several hours at the current which it will normally carry. This is a condition often encountered in railway work. Ten minutes of bucking snow, running with snow high enough between the tracks to rub on the motors, hauling cripples up a steep grade, running with one or two motors cutout—any of these may produce excessive temperatures with the inevitable result of damaged armatures and ultimate burn-outs.

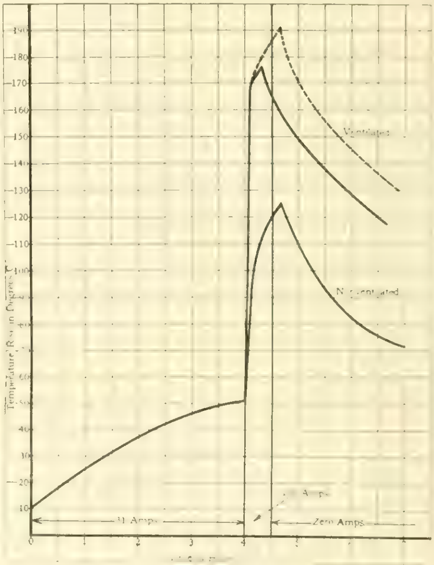

FIG. 2—COMPARATIVE TEMPERATURE RISES

Of the field coils of ventilated and non-ventilated motors having the same continuous capacity.

On some properties where trouble from short overloads has been experienced, it may be necessary to select future motors more liberally, for no railway motor is intended to buck snow or stand some of the overloads it will experience on poorly maintained properties. The operator must provide better snow fighting equipment, and must use it in a more efficient manner, if conditions are to be improved. Much can be done also in educating crews so that they may better appreciate the limitations of their motors. Better and more frequent inspection and overhauling will reduce the number of cripples by weeding out incipient cases of trouble.

The Logical Unit for Comparing Repair Costs

of Electric Locomotives and Cars

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TO ALL WHO ARE INTERESTED in the economical operation of electric railways, the cost of repairs to the locomotives and cars is of importance. Those charged with maintaining such equipment may be much helped by comparing their costs with those of other roads. Here one is confronted with the insufficiency of the usual units to which these costs are reduced. Usually, information is lacking which will enable useful comparisons to be made, except in the case of roads having practically identical equipment and service conditions. There are few roads so similar in these respects as not to require allowances and adjustments before a comparison of costs is of benefit. Costs of repairs are usually reduced to a locomotive-mile, car-mile, train-mile or ton-mile basis.

The locomotive-mile or car-mile as a unit takes no account of the weight or capacity of the locomotive or car nor of the character of the service. A large heavy car with electric equipment to correspond will eventually require more repairs per mile than a lighter one; a locomotive hauling heavy loads will require more repairs per mile than one in light service. Repairs are to a great degree dependent upon the work performed and a unit which does not provide for this is not satisfactory for the purpose of comparison. Often the record of mileage is not reliable, as certain dead mileage and short movements may be omitted, in fact it would be very difficult to include all these. In some services, this kind of mileage forms a relatively important part of the whole, while in other services it may be so small as to be negligible. Nearly all locomotives are required to do some switching but the amount varies widely in different services. If the amount is small, it is not included as mileage, and is sometimes omitted even when comparatively large. If it is sufficient to justify being recorded, the switching mileage is computed on an hourly basis at the uniform rate of six miles per hour. This has been shown to be quite wide of the mark in many cases. All of this means that not only is the recorded locomotive mileage quite usually incorrect, but that the extent of the error for some services is much greater than for others.

The train-mile unit has nothing to commend its use for maintainance of equipment records. Its only value is for comparing certain transportation expenses which are more a function of the train mileage than of anything else. Obviously the train-mile, since it makes no allowance for the great variation which exists in train weights, is as useless as a unit for comparing and analyzing repair costs as is the locomotive-mile.

The ton-mile is a better unit than any of the foregoing, particularly for freight service. It is a step in the right direction for it attempts to cover the work done. However, it is lacking in several important respects. To move a ton one mile up a grade imposes heavier duty upon all parts of the equipment, with consequent greater wear and tear, than to move a ton the same distance on level track or down grade. Yet the ton-miles are the same in both cases. Also a service involving frequent stops requires more from the equipment and imposes greater stresses and heating than does express service of the same ton-mileage. Mileage is one component of this unit and the record of ton-miles can therefore not be more reliable than that of locomotive-miles which, as has already been shown, is inaccurate. In addition, the record of the tons hauled is not always accurate and still worse is usually not defined. It may be gross tons, including weight of locomotives, cars and contents; gross tons, not including weight of locomotives; net tons, or contents of cars only; or revenue tons, which are net tons exclusive of certain non-revenue loads. Perhaps, because of lack of complete information, the tonnage on a division may be prorated on the basis of the system average, and thus be very much too high or too low because of some characteristic of the division's service which differs greatly from the average of the whole system. In passenger service, it is not always made clear whether ton-miles include weight of passengers, though this does not usually introduce any great error.

The kilowatt-hour input to the locomotive or car, though seldom used, is thought to be a much more correct and convenient unit than any of those discussed. The locomotive or car is a device whose duty it is to do work and we are concerned with what it costs to maintain it in proportion to the work it does. A part of the work of the locomotive is to move itself, the balance is to draw its load. Likewise a part, and a large part, of the work of a car is to move itself and the balance is to move its load of passengers or freight. There is no convenient method of segregating this, as the ratio between the gross and net weight is constantly varying. We are hardly concerned with this distinction. The propelling and controlling apparatus, including motors, gears, rods, brakes, etc., are required to do both portions of the work and are entitled, when comparing their performance, to be credited with the whole. So it resolves itself into taking the input to the device as the proper unit by which to measure what it has done. It may be said that this is putting a premium on low efficiency but there is little to that, as the efficiencies of cars and locomotives do not vary greatly when performing the kind of service for which they are designed. When required to perform other service in which the losses may be higher, these very losses are cause for repairs in that the heating of motors, resistances and control contribute eventually to repairs. The use of the input is therefore entirely just and logical as a unit for comparing cost of maintenance.

There are undoubtedly some items of repairs which are nearly if not quite independent of the work done. Painting for instance is more a function of time than of work done or miles run. There are a few others which probably depend principally on mileage, such as wear of pantagraph or third rail shoes, although the life of these, and still more, of the trolley wheels, is affected by the amount of current collected, that is, the work done. Even for these items, since mileage is one component of the work done, the input as a unit is not far wrong. But such items are not the major ones. Repairs to motors, control, brakes, trucks, frames, gears, pinions and even wheels and bearings are largely dependent upon the load as well as mileage, that is upon the work done. Under heavy loads all parts are continuously stressed to near their maximum and while so stressed the pounding and racking due to passing over frogs and switches results in greater wear and deterioration than when an equal mileage is made under light load.

Where electric locomotives are double-headed, the mileage of each locomotive is recorded. Were it the policy of the road to run these multiple-unit, calling the two units one engine, the mileage would be but half that in the former case and repairs per locomotive-mile would therefore be doubled. Yet the repairs per kilowatt-hour input would be the same either way.

It is certain that, if the cost of repairs were presented on a kilowatt-hour basis, there would not be such a great and, to some, puzzling difference as exists in the customary figures per locomotive-mile for different roads, and a better indication would be secured of the merits and suitability of the different locomotives for the work they are required to do.

It must be realized that even when reduced to the most rational unit any comparison between the cost of repairs to equipment, without allowance for different conditions surrounding its operation, is almost without value and leads to no dependable conclusion. Figures based on short intervals of time, such as the month, may be misleading because of accumulation of deferred work and the entering of delayed charges and credits. All of these are smoothed out when a longer period is taken. The average for a year should be taken, and even a longer period is preferable. The history of the equipments' operation, both during and prior to the period represented by costs under examination should be known. Overloading, either past or current, is reflected in the costs. Careful regulation against overloading now will not prevent past abuse from affecting present repairs. The correction of defects in design or workmanship may be spread over a long period and, though the correction may be fully sufficient and such equipment as is corrected may be cheaply maintained, the cost of the correction, together with the unsatisfactory performance of the equipment not yet changed, may result, during a prolonged transition period, in an average cost even greater than before any correction was applied. The very fact that a road has run during the year with little or no trouble may indicate that the year's figures for repairs cannot safely be taken as representing what may be expected in the future. Experience has shown that certain classes of apparatus have a more or less definite period of life after which they will fail and require repairs or renewals. If very well made and handled the time for repairing will be deferred for a longer time but, when it does come, the cost during that year will be high and will raise the average of the preceeding years. Also the reverse of this condition is met with. It may be that a number of alterations are early found to be desirable and for a period of perhaps several years the repairs include the cost of alteration as well as of the continued abnormal failure of those parts not yet reached in the schedule of alteration. In such cases the costs of repairs are higher than the average will be over a period long enough to include several years operation after alterations are completed and, therefore, should not be taken as representative of the type of equipment used.

Were it the custom to reduce the cost of repairs to the kilowatt-hour basis, we would soon be familiar with a proper figure to use for this item when estimating the cost of operation of any proposed electrification. At the time of making an estimate of this kind it is necessary to determine the energy required to perform the assumed service in order to determine the cost of power, and having this the cost of repairs could be estimated more accurately than by applying some figure to the calculated locomotive-mileage. The record of kilowatt-hours input is more easily kept than the record of locomotive or ton-mileage. Of course it requires that each unit be provided with an integrating wattmeter, but this is not now unusual and there are other good reasons for doing so. Probably the roads would continue to keep their present mileage and tonnage records for other purposes, but the suggested record would be of real value to them, both to check their own costs from time to time for different divisions or types of equipment and to compare their results with those of other roads.

An incidental advantage of this custom, which is of considerable value, is that it enables the shopman to know promptly the kilowatt-hour record of any unit. Now, it is very difficult and often impossible for him to keep the mileage record of any piece of the equipment which may from time to time be changed from one car or locomotive to another. The mileage record at best only applies to the main unit, the car or locomotive as a whole, and the mileage of certain trucks, motors, axles or wheels is very difficult to follow. Were it only necessary to read the wattmeter at the time of making each change the record would be comparatively simple.

There can be no question that, with proper but moderate attention to the instruments, the wattmeter record would be more accurate than the present mileage records, and would include all work done by the unit, whether light or loaded, revenue or deadhead, switching or road. It would add no appreciable burden to the crew or clerical force to keep this record, no important expense to provide and maintain the instruments. It would aid in keeping shop records and above all, would give a basis for intelligent comparison of different equipments which is not afforded by the present methods.

Electrification of the Central Limones, Cuba

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IN THE electrification of an industrial plant, where the material passing through manufacture is large in bulk or weight, and gathered from the surrounding territory—or in the construction of a modern plant of such a character, serious consideration should be given to the railway hauling the material to the plant. A power plant, generating electric power for the usual industrial applications will, of course, favor the further application of electricity to the railway. In addition, electric locomotives have inherent operating characteristics which make the application of the electric locomotive profitable. Some of these characteristics are:—

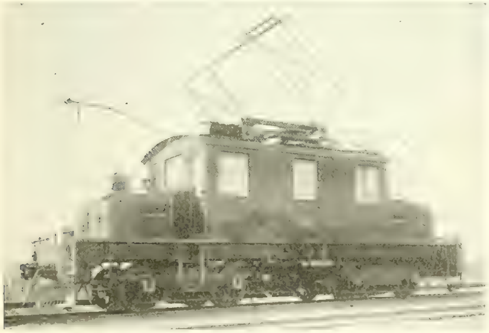


FIG. 1—TYPE OF LOCOMOTIVE USED BY THE CENTRAL LIMONES RAILWAY SYSTEM

1—Low standby losses, which consist mainly of losses in the blower, compressor and cab heating and lighting devices. These, in most cases are much less than the standby losses of the steam locomotive.

2—The cost of power per horse-power at the locomotive is less, due to the application of mechanical firing devices at the power house, larger generating units, and an organization particularly directed to get the most power from the fuel at the least cost.

3—There is no throwing of sparks, or dropping of hot ashes or smoke nuisance. Electric locomotives can haul directly into a plant with entire safety and cleanliness.

4—The electric locomotive is wholly an application of power in a definite service, and requires no fuel and water to be carried.

Undoubtedly, considerations of this kind entered into the decision to electrify the railway of the Central Limones in Cuba. This railway is in the province of Matanzas and operates through a limited territory. It comprises three main lines radiating from Central Limones with several branch lines running out from them. Two of the main lines connect with the Ferrocarril Unidos de la Habana. The total single-track mileage including the sidings and yards is 32.6 miles. During the grinding or cane season, comprising 130 days, cane is gathered from the surrounding territory and moved to the sugar mill at Central Limones. This with fuel and merchandise makes up the traffic into Central Limones. Stone is shipped throughout the year from a quarry north of Central Limones to Limonar, one of the connecting points with the Ferro-carril Unidos de la Habana, and in addition, sugar and molasses during the grinding season. The daily tonnage of revenue traffic is approximately 5000 tons during the grinding season and 1550 tons during the dead season.

The sugar mill erected at Central Limones is equipped with steam driven devices. Most of these are being changed over to electric drive and eventually all devices will be so driven. A refinery now under construction will be equipped altogether with electric drive. There is also a cement mill under construction at the stone quarry, which will require about 900 kw.

During the grinding season, bagasse, the refuse of the sugar cane after the juice has been squeezed out, is burned under the boilers, supplemented by oil and wood. During the dead season, Mexican fuel oil is burned and during the year 1918-1919 was obtained at $1.20 per barrel. Of the power generated, approximately 500 kw will be available for the railway during the grinding season. Much less is required during the dead season, when the traffic is relatively light.

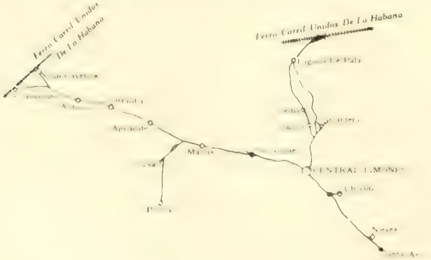
Under steam operation, two large and two small engines handle the switching at Central Limones. Six road engines, two switchers and one pusher are engaged at other points. The locomotives burn Clinchfield and Westmoreland Coal which, during the year 1918-1919, was obtained at an average price of $15 per long ton.

The electrification includes the installation at Central Limones of two 1875 kv-a, three-phase, 60 cycle, 480 volt, turbine driven generators; four 500 kv-a, single-phase, 13 200 volt, high tension transformers (one spare) for power at the cement mill; two 500 kv-a oil insulated, self cooling three-phase transformers, single primary, double secondary; two 500 kw rotary converter sets, each consisting of two 250 kw, 750 volt converters, operated from independent transformer secondaries, and in series on the direct-current side for 1500 volts. One transformer and one rotary converter set are sufficient to carry the contemplated railway load—the other set being spare. Space is provided in the power plant for the future installation of another turbo-generator to take care of possible requirements. A nine panel switchboard provides for the control of the generators, transformers and rotary converters, and in addition controls two 625 kv-a, three-phase outgoing feeders and three 1500 volt direct-current feeders.

FIG. 2—LOCATION OF CENTRAL LIMONES, CUBA

The breakers in the alternating-current circuits are remote mechanically operated, mounted on a pipe structure behind the switchboard and arranged to prevent a heavy concentration of current in the bus-bars, by having the feeder circuits tap off between the generator bus connections.

The overhead distribution for the railway is sectionalized, so as to be fed by three separate feeders. Catenary construction is used on the three main lines and on spur tracks where possible. The direct suspension type is used on tracks around the mills and on such sidings and spurs where the track curves are too sharp for the catenary construction to be economical. Two features of the catenary system are worthy of attention. Advantage has been taken of the absence of sleet to space the supporting poles farther apart than is the ordinary practice. On tangent tracks, poles will be spaced 60 meters (200 feet) and 30 meters (100 feet) for the catenary and direct suspension construction respectively. This spacing is approximately one third greater than ordinary and affects an appreciable saving in number of poles and erection costs. The second feature is that no separate feeder is run along the line, but instead, where a feeder is necessary, it is used as messenger for the catenary.


Ferro Carril Unidos De La Habana
Ferro Carril Unidos De La Habana
CENTRAL LIMONES
FIG. 3—[illegible] CENTRAL LIMONES RAILWAY

There are five electric locomotives under construction. Under normal conditions, one of these locomotives will be a reserve unit, even during the grinding season. Each locomotive will have a weight of 40 short tons, all supported on the drivers, and will be equipped with four 95 hp, 750 volt field control motors, connected permanently two in series and arranged for forced ventilation. The gear ratio will be 15:62 and 33 inch wheels will be used.

The motors may be operated all in series from the 1500 volt trolley for half speed, or in series-parallel combination for full speed. To permit a larger tractive effort and drawbar pull, the motor fields are provided with taps which permit part of the turns to be cut out in both the half speed and full speed running combinations of the motors, thus securing four economical running speeds.

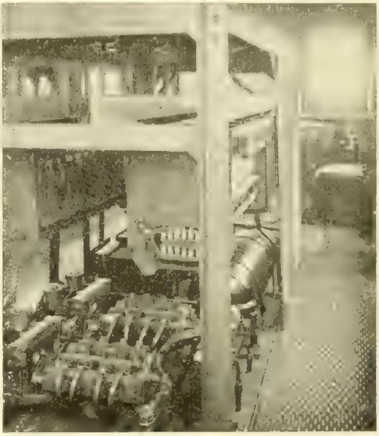


FIG. 4—EQUIPMENT COMPARTMENT IN LOCOMOTIVE OF THE TYPE BEING BUILT FOR THE CENTRAL LIMONES

At its continuous current rating, each motor is capable of giving a tractive effort of 1800 pounds, with the specified wheel diameter and gear ratio, or 7200 pounds total for the locomotive, at a speed of 16 miles per hour. For short periods, the motors are capable of operating at approximately twice the one hour rating, or 220 amperes. However, the most severe operating condition which these locomotives will be called upon to meet is hauling a 12 car loaded train (360 trailing metric tons) up a two percent tangent track. This requires a locomotive current of 320 amperes—with motors in the series-parallel combination and operated with full field, resulting in a current per motor of 160 amperes. Advantage is taken of the full field notch on short heavy grades to keep the power demand to a minimum.

The mechanical parts of these locomotives may be considered under four heads, motor trucks, brake rigging, the cab or superstructure and equipment supports.

The trucks are two in number, each with two driving axles, and are of the rigid bolster, equalized type, and built with rolled steel side frames located outside the wheels. The wheels are also rolled steel.

The brake equipment consists of pneumatically-operated brake rigging with shoes on all wheels and hand brakes operating on all wheels. The brake rigging is actuated through a radial brake beam which permits effective braking on short curves. The equipment is arranged for double end operation, and is an adaptation to the electric locomotive of the standard brake equipment applied to steam locomotives. It includes an independent (straight air)brake for handling the locomotive alone, together with the standard quick action automatic brake for both locomotive and train. The brake air cylinder is mounted under the cab, and the brake lever and size of cylinder are so proportioned that with 50 pounds air pressure in the brake cylinder, a total normal shoe pressure of 75 percent of the weight of the locomotive is obtained.

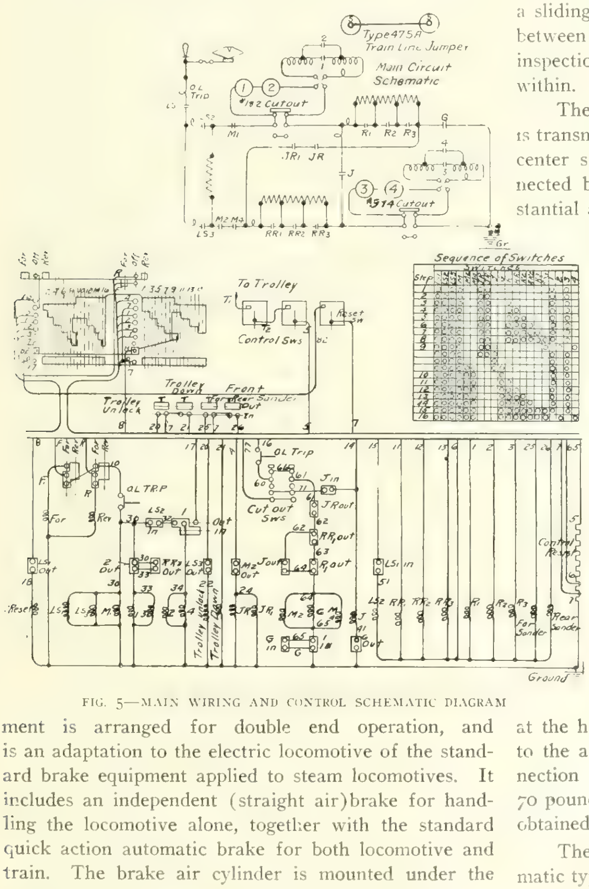


FIG. 5—MAIN WIRING AND CONTROL SCHEMATIC DIAGRAM

The four motors are inside hung, that is, hung between the driving axles, one end being supported on the truck bolster and the other being supported around the axle. A pinion of 15 teeth attached to each motor shaft engages a gear of 62 teeth on each driving axle. The gear ratio is such that a high drawbar pull may be realized. The motor case is provided with an opening to which a flexible canvas connection is made leading from an air duct for ventilation.

The cab is substantially built of steel, well finished, thoroughly braced and fastened and provided with a wooden floor. Walking platforms outside the cab are of rolled steel checker plate. Three windows are provided on each side and a door and two windows at each end. The hoods at each end have hinged doors on each side which can be opened to permit inspection of the compressors, blowers and headlight resistance mounted under the hood. This provision, together with a sliding door on the hood front and a removable plate between the cab and hood interiors, therefore, permits inspection on all four sides of the apparatus mounted within.

The underframe through which the drawbar pull is transmitted is built up of rolled steel channel side and center sills with plate end sills. These sills are connected by heavy knees, making an exceptionally substantial and rigid structure.

The air duct is an enclosed space between the center sills, guiding the air from the blower under one hood to openings adjacent to each motor to which the canvas air connections are jointed. The blower is driven by a 1500 volt double commutator motor, controlled through fused canopy switches.

In the other hood two compressors, driven by 1500 volt motors, are mounted and controlled through fused canopy switches. They supply air between 85 and 100 pounds pressure to the air tanks or reservoirs under the cab. Cooling pipes are inserted between each compressor and the air reservoirs, and also between the reservoirs. The compressor governor is set to operate at 85 and 100 pounds, so that it will automatically cut in the compressor at the lower pressure and cut it out at the higher. A pipe leads away from the reservoirs to the air distributing valve and brake valve. A connection is also made through a reducing valve, set at 70 pounds, to a control reservoir from which the air is obtained for operating the electric switches.

The electric control is of the standard electropneumatic type, in which the switches are closed and held in contact by air pressure applied through a valve, which is opened electrically and closed by a spring when the valve coil is deenergized. The valves are actuated by low-voltage current through a master controller at either end, under direct and easy control of the engineer. The switches are combined into two compact groups, and with the accelerating resistor, reverser and control resistor, are mounted in an equipment compartment of structural steel, erected between the floor and roof of cab and rigidly braced. An expanded metal screen is provided around the structure to prevent accidental contact with the electrical apparatus.

The master controller is of the usual type of construction, comprising a speed drum and reverser drum, finger boards and handles.

The switches and reverser are provided with interlocks to prevent a false operation occurring during the various switching and transition steps. For example, to reset the overload device, it is necessary to bring the master controller to the off position in order to complete the reset circuit, which lifts the plunger and contact discs into position, and completes the main control circuits. Again, throwing the reverser handle one way or the other does not operate the reversing switches. This is accomplished only when the controller is moved to the first notch. The complete operation of the reverser then closes the main switches, putting the motors in series with the accelerating resistor across the trolley voltage. Interlocks on the switches insure that the switches will close in the proper sequence to give the connections indicated by the position of the master controller handle.

The accelerating resistor consists of cast-iron grids assembled into frames, and mounted in the equipment structure on insulated bolts. The resistor is designed so that an acceleration can be made smoothly and is of sufficient capacity to dispose of the heat losses during acceleration.

The cab lights and headlights are operated from the middle tap of the double commutator motors operating the blower. These circuits are controlled through snap switches mounted on the meter panel. The blower, compressor, control and reset switches are mounted for easy operation by the engineer.

The current collectors consist of one pantagraph and two wheel trolleys; the latter being for forward and reverse running, in case the pantagraph cannot be operated. The trolleys and pantagraph are of standard types. The pantagraph is spring raised and air lowered. In the down position, the pantagraph is held by a latch which is released by air to raise the pantagraph, the spring of the pantagraph completing the movement. In lowering the pantagraph, air pressure is used to overcome the force of this spring.

Result of Twelve Year's Heavy Haulage

On the Single-Phase Electrification of the Grand Trunk Railway System

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Detroit, Mich.

SINGLE-PHASE electric locomotives were placed in service in May, 1908, for the purpose of hauling freight and passenger trains through the St. Clair Tunnel, under the St. Clair River, connecting Port Huron, Michigan, and Sarnia, Ontario.* The tunnel is a single track tube, 6032 feet in length, with approaches totaling 5784 feet. The track enters the tunnel from the Michigan portal with a descent of two percent for 2399 feet, then graduates to 0.1 percent for 1718 feet and then takes a two percent grade for 1915 feet to the portal on the Canadian side.

The locomotives haul trains of 1000 tons up these two percent grades at a speed of ten miles per hour. They are doing more than was ever possible with steam and at less cost. The service rendered by both the power plant and the electric locomotive equipment has been such that during the entire twelve years of operation, delays of even a few minutes have been almost unknown. Some delays, due to insulator failures causing short-circuits, occurred at first, but this trouble has practically been eliminated by changing the design of some of these devices. The only trouble since these changes were introduced has been due to rare mechanical and accidental injury.

THE LOCOMOTIVES

There are six units, each weighing 66 tons and mounted on a frame which is non-articulated from end to end. None of them have shown any signs of weakening. Each locomotive, two units, has a rating of 1500 hp, and a maximum safe speed of 30 miles per hour. Each unit has three single-phase railway motors, each of which is directly connected through a single gear and pinion to a pair of 62 inch drive wheels. Considering that no quills or springs are used to absorb the shocks, the performance of the gears and pinions has been exceptionally good. A number of the original gears are still in service and in good condition after having made 432 000 miles. Some of the pinions have made more than 150 000 miles and are still in good condition.

Drive Wheels—At first, considerable trouble and expense was experienced with the wheels due to abnormal flange wear, which was caused to a large extent by the rigid wheel base and the great number of curves and switches encountered. The mileage never exceeded 25 000 before it was necessary to remove the wheels for turning. In July, 1910, Mr. W. D. Hall, Superintendent of the tunnel, conceived the idea of an atomizer to spray oil on the wheel flanges by means of compressed air. This is accomplished by pressing a button in either of the controllers, one of which is at each end of the cab. The oil is applied as the locomotive approaches a curve and then only for a very short duration of time. The results have been so remarkable that the tires of No. 9 pair of wheels of locomotive No. 2658 have made a mileage slightly exceeding 300 000 miles since they were in a lathe for turning.

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*[illegible] Six Years Heavy Haulage" by W. D. Hall in the JOURNAL for Dec. 1910, p. 542.

It is found that the mixture of oil and air not only lubricates the flanges, but cleanses them from grit and sand. Another feature of this lubricating device is that no attempt is made to heat the oil and blow it through the frozen nozzles in winter. On the contrary the lubricators are placed outside on the locomotive frame. The oil is thinned to suit the temperature conditions, so that it is sprayed nearly as well in winter as in summer. This device alone has naturally brought about a very considerable saving in both labor and tires.

One of the very important features of operation by electric locomotives is that they are available for service at least 90 percent of the time. The electric locomotives on this property have more than met this average.

Pantagraphs—Each unit is equipped with one pneumatically-operated pantagraph which is controlled from the engineer's cab. With a reasonable amount of attention these have given very little trouble. Breakages usually occur as a result of the shoe catching in some part of the overhead construction, but such trouble is rare.

The pantagraphs collect the current from a catenary overhead construction, supplemented with a steel contactor wire on the grades, at 3300 volts, 25 cycles. The same voltage is used direct from the power plant, which is located near the portal of the tunnel on the Port Huron side.

Autotransformers—After the current is collected, it passes to the autotransformer, which is located on one side of the cab. During severe electrical storms two of these transformers were damaged, but repairs were made without removing them from the locomotive. This shows the ease of accessibility which obtains in these cabs, because of their good layout.

Switch Groups and Controllers—The switch groups are located on the side of the cab opposite the transformer, which gives a very wide aisle in the center of the cab, running its full length with a large amount of space at either end. The cabs are surprisingly roomy.

The contacts in the switch groups require occasional scraping, and the shunts are renewed from time to time, but all in all, the smallness of the amount of burning is remarkable. The valve parts require little attention. An air compressor oil is used which does not cause gumming of the small parts.

The controllers are of the locomotive type, with short angular movement, and the number of accelerating resistance steps provided gives a very smooth acceleration without slipping the wheels. The controllers require little attention and have given practically no trouble.

Main Motors—The field windings have given no trouble at all but some armatures have been repaired from time to time. The commutators have made more than 400 000 miles each, yet not one has been renewed. Arrangements are now under way to start renewals, so that no trouble will be met in a year or two, due to the necessity of renewing a number of commutators at one time. Practically all the motors have made the same mileage, and the wearing parts have held up very uniformly. Some of the commutators have exceeded 100 000 miles since last being turned and slotted. The brush mileage varies between 40 000 and 60 000 miles. No shunts or caps are used with the brushes, but the finger tips are practically the full width of the brush.

Air Compressors—The air compressors have given satisfactory results. They are equipped with electrically controlled governor synchronizers, which cause both compressors to start and stop at the same time for double heading operation of the locomotives.

Locomotive Auxiliaries—The air compressor and blower motors have given splendid service. The latter have not required repairs to either the stator or rotor windings. Only three armatures of the former have been repaired, and one of these had the canvas heads renewed only. The commutators are cleaned from time to time, but it is not necessary to dress them in a lathe.

POWER PLANT

The two main units are Westinghouse three-phase, 25 cycle, 3300 volt turbogenerators, two barometric condensers, two engine driven exciters, one motor driven exciter and two air pumps. In the turbine room basement are two engine driven circulating pumps of the centrifugal type, one house pump, two engine driven stoker fans, the transformer room, a store room and a mercury arc rectifier. The boiler room contains four water tube boilers equipped with underfeed stokers, an independently fired superheater, overhead coal bunkers and two feed water pumps.

Turbines—The turbines have given very satisfactory service during the twelve years. No bearing trouble has been experienced. In fact, the oil stone marks on the spindles are just about as fresh as when they were made twelve years ago. Some of the steel blading has been removed and as the small or high pressure blading was not laced it has been found advisable to replace the small unlaced steel blading with laced bronze blading. The turbines take the irregular loading in a wonderful manner, and the vibration throughout the variations is almost unnoticeable.

Main Generators—The insulation of the fields gave evidence of breaking down after about six years' operation, at which time they were rebuilt with more modern insulation. They have given splendid service since that time. The stator coils have not given any trouble whatever, although frequently subjected to severe strains.

Exciters—The motor driven exciter unit has given excellent service. It has been in continuous operation, night and day, for twelve years with exception of a few minutes each week for inspection and dusting. The commutator of the direct-current generator has never been turned or dressed since being slotted about eleven years ago. During an electrical storm, one or two coils in the motor broke down, but were repaired in short order and the set put back in service.

The Condensers and Circulating Pumps have required the ordinary running repairs only. For a short period at the start, the condensers caused a little trouble due to the spray nozzles becoming clogged with small fish during certain seasons, as the water was taken directly from the St. Clair River. This was overcome by removing the grids from the nozzles, thus permitting the fish to go right through with the water.

The engines of the engine-driven circulating pumps have received only the ordinary repairs and the pumps show practically no sign of wear. In fact the paint with which the impellers were originally painted is even now quite fresh.

Boiler Feed Pump and House Pump—The boiler feed pumps are of the reciprocating type. They have received frequent repacking and renewals of parts. Water for sealing the turbine glands and various parts is supplied by a house pump of the reciprocating type. In order to avoid trouble, due to loss of vacuum on account of failure of the water supply, the discharge pipe of the pump is connected with the city supply line, but interposed by a check valve. Hence, by maintaining a slightly higher pressure at the house pump than that of the city line, no water from the city system can pass. Should it be necessary to stop the house pump, or should it fail, the check value will open and thus an uninterrupted supply of water is maintained. This little detail in itself is a great precaution, and is just one of the characteristic features of this whole installation which guards against any accident that will tie up the system.

Boilers and Stokers—The boilers and stokers have given very satisfactory results, especially in view of the fact that they have had to care for very erratic load conditions. A few tubes have been renewed during the twelve years and the furnaces have been repaired from time to time. It is probable that it would not have been necessary to have renewed even these few tubes if slack coal could have been used at all times. On account of the very sudden demands for power it is necessary to use high air pressure, so that when crushed mine run is used a blow torch effect may be set up to such an extent as to result in the blistering of tubes.

Although working under widely fluctuating conditions of load, not one retort was burned out and not one renewed in a period of eleven years. At the end of this period all the retorts were renewed, because they were worn out by the action of the rams and corrosion, where they were set in the brickwork at the front end. The boilers and stokers have been in 24 hour service since November, 1907, only being out of service during regular cleaning and inspection periods.

TROLLEY LINE CONSTRUCTION

The trolley and messenger wires are supported on steel bridges, which are spaced at 250 ft. intervals. The trolley wire is suspended from the messenger wire by catenary hangers spaced every 13 feet. This has given very satisfactory results. The greatest wear was found at points of rigid support. At these points an iron trolley wire was installed beneath the copper, and this has given satisfaction, especially where it is not exposed to steam locomotive gases.

Train delays due to line material failures have been so few as to make them almost negligible. Especially has this been true during the last six or seven years of operation. During the first few years a few short-circuits and consequent delays were experienced, due to insulator failures, which usually resulted from steam locomotive gases causing flashovers. These have been overcome by installing two insulators in series where locomotive gases are found. At first there was some insulator trouble in the tunnel due to unequal expansion and contraction, but this has been overcome by installing insulating devices of newer design.

Another source of trouble due to short-circuits was brought about by birds alighting on the lightning arrester tips. As it would be a difficult matter to educate the birds, perches were provided above the arrester tips for the birds' convenience, and in this manner the trouble was overcome.

DETROIT EDISON SERVICE

Arrangements have been completed with the Detroit Edison Company to supply power for the tunnel operation. A Westinghouse synchronous motor-generator set with a capacity of 2860 kilowatts has been installed in the substation, which stands just north of the power house. The motor operates at 4600 volts, 60 cycles, three-phase, and the generator furnishes single-phase, 25 cycle current at 3300 volts to the tunnel trolley. The train load reaches a four to six minute peak of about 2400 kilowatts. Both the motor and generator sides of the machine have separate exciters at the respective ends of the shaft. Both exciters are equipped with automatic regulators. The motor exciter regulator takes care of the power-factor and the other regulator takes care of the generated voltage.

RESULTS

The average cost of maintenance of the electric locomotive equipment, material and labor up to December, 1914 was 4.514 cents per locomotive-mile, and from December, 1914 to December, 1919, 7.051 cents per locomotive mile.

The fact that the electric locomotive equipment, the power plant equipment, and the line material are in splendid operating condition today, not only speaks well for both the design of the various parts and the quality of material used in their construction, but also for the maintenance and supervision given them during these twelve very successful years of operation. This installation proves the value of single-phase electrification and the results obtained very clearly show that alternating-current is not an experiment. It has proved its worth on this property, just as it has on many others throughout the United States and foreign countries.

The New Liquid Rheostats

For the Norfolk & Western Railway

D. C. WEST
Railway Engineering Department,
Westinghouse Electric & Mfg. Company

THE TONNAGE handled per day by the split-phase locomotives on the Elkhorn Grade electrification of the Norfolk & Western Railway, is greater than that on any other electrified railroad, either in this country or abroad, and the nature of the service demands that all equipment possess the greatest stamina. Accelerating rheostats must be able to handle frequent and heavy accelerations, after the heavy tonnage trains have been stopped to fill out the load at several points along the grade of one to two percent on the western half of the line. Because of its high thermal capacity, its ability to dissipate large amounts of heat quickly, and the characteristic smoothness of its resistance variation, the liquid rheostat has demonstrated its inherent suitability for this very severe service. Five years of operating experience have only suggested certain modifications and refinement in design, and these are incorporated in the new rheostats.

The rheostat for each truck consists of two electrode assemblies, of three electrodes each, mounted side by side in a rectangular tank, which is provided with a set of weirs for raising and lowering the height of the electrolyte around the electrodes. The electrolyte is contained in a tank directly below the rheostat, and is circulated through the rheostat by a motor-driven centrifugal pump. A bypass is taken off the pipe leading from the pump to the rheostat, and through this a portion of the electrolyte is shunted into the cooling tower. From the cooling tower, which is located beside the rheostat, the electrolyte returns to the electrolyte tank to be circulated again. Beneath the cooling tower and adjacent to the electrolyte tank is a tank carrying a supply of fresh water, the function of which will be described below. The complete outfit stands about six feet high from the bottom of the tanks to the top of the cooling tower, and covers a deck space about four by five feet.

The general arrangement of the electrodes and regulating weirs is shown in Fig. 1. The electrodes *A*, *B* and *C*, are connected to the slip rings of the main driving motors through the insulated terminal bolts *D* which extend through the top plate and also serve to support the electrodes mechanically. The lower ends of the electrodes rest in grooves in the soapstone blocks *E* which hold not only the electrodes in place, but also insulate them from the bottom of the tank. The ground plates *F* are supported from the side and central ground plates *G* and *H* by means of the through bolts *J*, which are provided with iron pipe spacers for locating the plates in their correct positions. Both the electrodes and the ground plates are of steel sheet and the construction is such as to give a light and very rugged unit. There are two three-electrode units in each rheostat, and either may be readily removed for inspection or repair by taking off the removable side plate *R* and sliding the unit out into the compartment at the end of the cab.

At minimum level, i.e., on the first notch of the master controller, the path of the current is directly through the electrolyte from *A* to *B*, *B* to *C*, and *C* to ground to *A*. The lengths and equivalent cross-sections of all three paths between electrodes being equal, a balanced three-phase delta resistance is obtained. The high resistance necessary to limit the current at start is obtained at this level by the wide spacing of electrodes, by the narrowing in of the electrodes at the bottom and by the use of soapstone barriers *K*. These barriers have the effect of increasing the length and restricting the cross-section of the current path, and thus increasing the resistance between electrodes without increasing the current density on the surface of the electrodes. The very low maximum current density, and the fact that no circuits are completely broken between the electrodes and the electrolyte, eliminate any possibility of arcing, and consequent burning of the electrode tips.

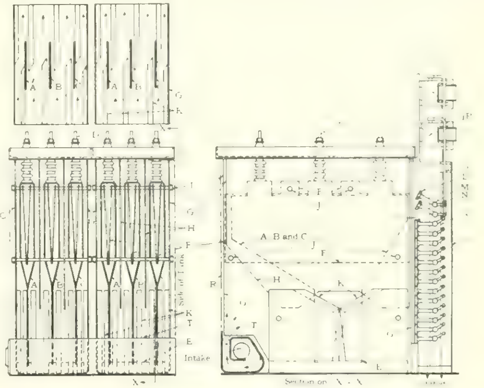

FIG. 1—GENERAL ARRANGEMENT OF ELECTRODES AND REGULATING WEIRS OF LIQUID RHEOSTAT

As the locomotive is accelerated, the secondary voltage of the motors gradually decreases, and the resistance in circuit must be decreased in proportion in order to maintain the current, and hence the tractive effort constant. This reduction in resistance is accomplished in the liquid rheostat (1) by increasing the submerged area of electrodes, (2) by increasing the number of paths which the current may take between phases, and (3) by decreasing the length of these paths.

As the electrolyte rises from its minimum level, the delta resistance is lowered by the increasing submerged area, and by the sloping off of the soapstone barriers, so that they cause less restriction of the path. At a point about six inches above the minimum level, the solution begins to cover the ground plates *H*. This affords the current two short parallel paths from each electrode to ground, giving a low resistance star connection in addition to the comparatively high resistance delta circuits already established. Sudden change in resistance, and concentration of current in the electrolyte opposite the center of the electrodes, is prevented by cutting the ground plates away in the center. As the electrolyte rises still higher, the paths are shortened by branching the electrodes out so that they come closer to the ground plates on either side. Another ground plate *F* is brought in between the two branches of each electrode, giving a total of four parallel star paths. The resistance in the circuit at the maximum level is thus reduced to such a value that when the motor secondaries are short-circuited on the last notch of the master controller, there will be only a small percentage change in tractive effort.

The means for controlling the height of electrolyte in the new rheostat has been designed with particular attention to positiveness of operation and ease of maintenance. It consists of a series of fifteen long, narrow segmental weirs *L*, extending lengthwise across the tank along the edges of the electrodes, and resting one on top of the other. These weirs may be raised and lowered individually by manipulation of the master controller.

With the pump running and all weirs in the *up* position, the electrolyte flows in through the flow equalizer *T*, across the rheostat between the electrodes and barriers, and out beneath the bottom weir. When the bottom weir is lowered to the *down* position, the electrolyte must rise until it flows over the top edge of the weir. This is repeated, as each weir is lowered so that its bottom edge rests directly on the top edge of the weir below it, until, with all in the down position, the weirs form a solid wall across the end of the tank, and cause the electrolyte to rise to its maximum level. Thus, as each weir is operated it establishes a new and exact level of electrolyte, and hence an exact value of resistance in the secondaries of the motors. The change from one step to another, however, is always gradual and smooth, corresponding to a large number of very small intermediate steps.

Each weir is pivoted on an axis *M*, parallel to its longer dimension, with its ends supported in the bearing blocks *Q*. The bearing blocks are removable, so that the entire set of weirs may be taken out of the side of the tank as a unit, by first removing the side plate *S*. A short arm *N* projects out from the weir casting on the side opposite the face of the weir, and from this arm a connecting rod extends up to the piston of an air cylinder and magnet valve assembly *P*, similar to that used on a standard unit switch. The arrangement is such that when air is admitted to the cylinder, by energizing a finger on the master controller, the arm is raised and the weir lowered. In this way a given notch on a master controller speed lever always connects the same definite resistance in the secondaries of the motors which that lever controls. One set of weirs is provided for each of the four trucks on the locomotives, and each set is controlled by a separate speed lever on the master controller. The four levers may be notched up either independently or together, and the loads on the four trucks may readily be balanced, if necessary, by changing the relative angular positions of the levers.

A part of the energy consumed in the rheostat is radiated from the surface of the tanks, but the greater part is dissipated in the cooling tower. As mentioned above, part of the electrolyte coming from the pump is led off through a pipe to the top of the cooling tower. It then flows down in a thin sheet over a series of slanting metal trays, where some of the water is vaporized and passes off as steam through a vent in the side of the tank. A considerable amount of heat is required to convert the water into steam and, as this heat must be absorbed from the liquid which remains, the solution which flows back into the electrolyte tank is comparatively cool. By this method it is possible to dissipate a very large quantity of heat within a short period of time, and without any possibility of damage to the apparatus involved.

The evaporation of water from the electrolyte, however, causes an increase in density of the solution, with a resultant decrease in resistance at all levels. To compensate for this, a supply of fresh water is provided. Compressed air is used to force the fresh water into the electrolyte tank where it mixes with the electrolyte and reduces it to the proper density. The air is admitted into the space above the surface of the water in the fresh water tank through a small hand valve, and a gauge glass is provided on the electrolyte tank to indicate when the proper level has been reached. It is thus an easy matter for the engineman to maintain the density in his rheostats constant during the evaporation of the entire supply of fresh water. In addition, the rheostat is so designed that about one-third the normal weight of electrolyte may be evaporated without lowering the resistance beyond the allowable limit. Normal operation is at constant density, with a 35 percent reserve capacity available for operation at varying densities.

Winding Railway Motor Armatures

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INCREASED mileage per motor failure is the aim of every operating man. In addition to the standard cost of taking a truck from under a car, removing a motor and replacing with another, and making the necessary repairs to the damaged motor, the railroad must face the cost of public opinion. Every failure carries with it the possibility of a tie-up and disarranged schedule, resulting in dissatisfied patrons. Taking all things into consideration, a motor failure on the line is expensive. Realizing the cost of motor failures, it is good economics to employ all precautionary measures necessary to keep the motors in service. Failures can be reduced to a minimum with careful and intelligent inspection, and the life of the equipment increased by heavy overhauling at certain intervals, based on mileage.

In most cases, motor failures are due to armature trouble and the actual life of an armature, omitting failures due to mechanical troubles, depends upon the winding department. If they fail, all other precautions are useless. High-grade material and workmanship, even with higher cost, is the most economical in the end. Many points must be watched during the winding of an armature, if the best results are to be obtained. The methods to be followed and points to be observed to insure a high-grade product are given in the following paragraphs.

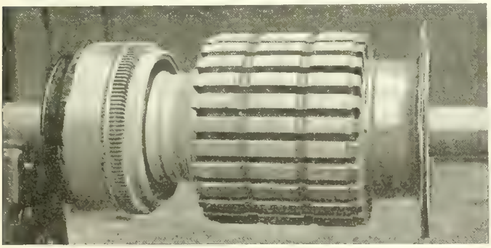

FIG. 1—METHOD OF INSULATING COIL SUPPORTS

INSPECTION OF CORE AND COMMUTATOR

Examine the condition of the iron regardless of whether the armature is new or old. Straighten up the laminations and file off all burrs and high spots that might damage the coils. Then inspect the commutator, making sure that it is tight. Remove any dirt or carbon dust that may be lodged between the mica V-ring and the ends of the bars. Renew the protecting band over the front mica V-ring when loose, oil soaked or damaged. If in good condition, thoroughly clean and re-varnish. In case the mica between the commutator bars is oil soaked, rebuild the commutator with new mica. Clean out the slots in the commutator neck, removing the old solder, for when they are not clean the necks will crowd when the leads are put in, and the forcing required to keep the necks straight carries with it the danger of breaking off the copper, especially on thin bars. Test from bar to bar with at least 110 volts to insure against possible short-circuits. Test for ground at a voltage of at least twice line voltage, to make sure of a sound commutator.

INSULATING OF COIL SUPPORTS

When the old insulating material is roasted or lifeless, due to age it should be renewed. Fig. 1 shows a method of insulating the coil supports of a typical wire-wound armature. On the pinion end, it is insulated with treated cloth caps, consisting of curved sections of treated cloth, held in place with treated cloth tape, which is used for insulating the coil support proper. A fullerboard ring is placed directly back of the commutator and the joint between the rear mica V-ring and fullerboard ring is sealed with several layers of treated cloth tape. Treated cloth tape is also used on the front coil support and is applied so as to make a fillet between the coil support and the fullerboard ring. Before winding, the space directly back of the commutator neck is filled with rope and cement or treated cloth so that the leads will not rest on the edge of the commutator slot.

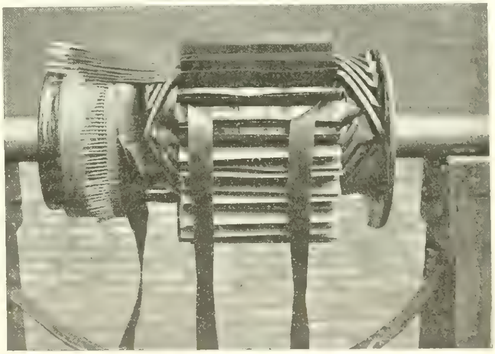

FIG. 2—ARMATURE PARTLY WOUND

LAYOUT OF ARMATURE

After insulating the core, and before starting to wind, the layout of the commutator and coil, should be checked. This is very important, as one bar off neutral may affect the flashing conditions of the motor to such an extent as to cause considerable trouble, the cause of which may not be discovered for some time after the armature is put in service. Armatures of either the two-circuit wave or multiple-circuit lap winding types, with brushes on the center line of the poles, have the center line of the coil throw in the slots lining up with the center line of the coil throw on the commutator. Most railway motors have the brushes on the center line of the poles, but, when they are offset, the center line of the coil throw on the commutator must be shifted a like amount to take care of it. When there is a dead coil in a winding it should be the first coil used, and after the lead is cut off it is considered the same as a coil with an odd number of active single coils. The manufacturers will gladly furnish the correct layout for any particular armature.*

WINDING

Watch each coil during winding, making sure that it is in its correct position before the next coil is wound, for if the coils start to crowd, the winding becomes difficult and damage may be done to the armature. This can easily be accomplished by keeping the diamond part of the coils lined up and the loops down in position. Do as little hammering as is necessary to get each coil into position. Winders should have a mallet with a head arranged for a raw hide insert on one side and soft rubber on the other. A fibre piece approximately the width of the slot and length of the core should be used for forcing the coils into the slots, and a fibre drift for keeping the diamond part of the coils in place. In no case should any tools be used in winding that have sharp corners which may damage the coils.

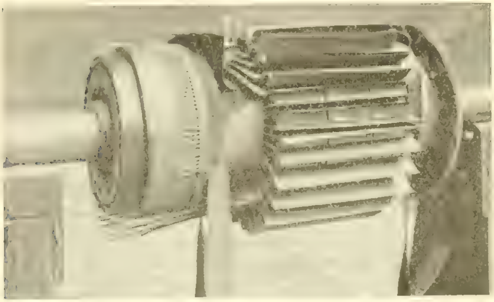

FIG. 3—METHOD OF INSULATING BOTTOM LEADS

Use fish paper U-pieces in the ends of the slots, where space has been allowed for them, and wind the coils in paper winding cells, if there is sufficient room. The coils should fit snugly in the slots to prevent vibration and, if necessary, filling pieces of fish paper or fullerboard should be used. When coils have been in storage for some time, and are dried out, heating will soften them and aid the winding considerably. Add additional insulation between the coils in winding, where high voltage exists, when there is danger of cutting due to vibration or pressure or when filling is desired. No set rule can be made regarding this point, as it depends on the particular type of winding. Place the leads down in an orderly manner, avoiding all crosses, and wherever there may be danger from cutting use protecting pieces. Use a light hammer or mallet to drive the leads into the commutator neck, driving the bottom leads down with the top leads and the top leads with the copper fillers or plugs. In no case use a tool for driving the leads down, as they may be damaged directly back of the commutator, where most broken leads occur.

The bands must be tight on the iron and at the same time exert a pressure on each coil, and when necessary to secure this condition, use fish paper or fullerboard strips between the top and bottom part of the coils in the slot. Bands on the end windings should also be tight to reduce the movement in the winding to a minimum. Care however must be taken not to crush the coils.

A partly wound armature is shown in Fig. 2. It has the U-pieces at the ends of the slots and is designed to be wound with a winding cell. The method of placing insulating material between the lower front diamond and the leads of the next coil is clearly shown. These pieces insulate the bottom leads from the coil proper, and after all the coils are wound, the ends of the insulating material are brought up over the end winding, and help to insulate between the coils and the top lead. The projecting pieces at the end of the diamond are also shown, as well as the method of placing layers of material between the top and bottom diamonds.

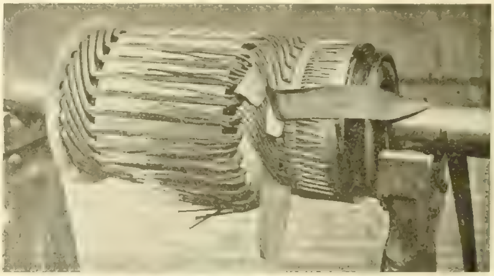

FIG. 4—METHOD OF INSULATING TOP LEADS

A method of putting down the bottom leads is shown in Fig. 3. The leads are put down in two layers and a piece of insulating material is placed between the leads where they go from one to two layers. Braid is interwoven between the leads directly back of the commutator neck.

A completely wound armature is shown in Fig. 4, with the winding cells cut off and part of the top leads in place. A piece of heavy paper is used to protect the adjacent coil where the leads cross. Tape is used to hold these pieces and the material over the ends of the coils in place, and to make a foundation for the leads.

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*For further information on coil leads see Railway Operating Data in the Journal for March, 1917.

The leads are put down in two layers, with braid between the leads of each layer and between the layers.

SOLDERING

Be very careful in soldering, not to get solder back of the commutator neck and between the leads. Although it may not show up as a short-circuit at the time, it may work into such a position as to cause trouble later. Good soldered joints are essential to avoid hot spots, running solder and failure. Alcohol and rosin or other non-acid fluxes should be used in soldering, as acid may get into the winding and destroy the insulation.

BANDING

Good armatures are often ruined by loose bands, which break and allow the coils to be thrown out of the slots. Hot banding and the use of strip tin under the core bands overcome this trouble to a large extent. The heating of the armature makes the winding more pliable and it makes a more compact winding when banded. When there is considerable give to the winding, temporary bands should be run on first to get the coils down into position before the permanent bands are placed. The reason for this is that the first turns of the band will be loose when the band is completed, as the last part of the band pulls the coils down farther and releases the pressure on the first turns. Core bands should fit tightly on the iron and at the same time exert a pressure on the coil. Tin strips run under the core band with sufficient clips makes practically a solid band when the wires are soldered. When extra insulation is used under the tin it should be very thin, so as to reduce the tendency of the band coming loose when the insulation dries out in service.

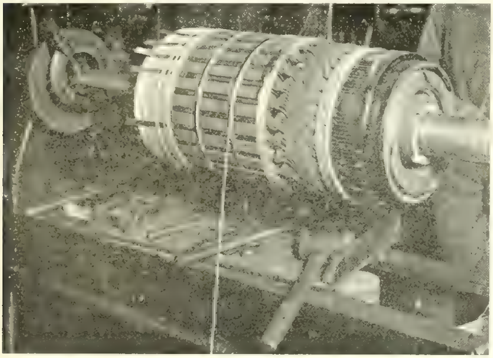

FIG. 5—BANDING

Fig. 5 shows an armature during banding. All the insulating material, the hood, the heavy paper on which the rear end band is placed, and the tin strips and clips are in place, and the second core band is being run on. The band on the front end of the core is temporary and is used to hold the coils down in position. The four anchor clips where each band starts and ends are clearly shown.

The illustrations show the winding and banding of a typical wire-wound armature. Ribbon and strap wound armatures are similar and the same precautions must be taken. In case of two-piece strap coils, with clips on the pinion end, it is necessary to keep the coils in place during winding, and this can easily be accomplished by the use of a winding jig, consisting of a circular steel plate, fitting over the shaft, and slotted around the periphery to hold the coils temporarily at the back end, the same as the commutator slots hold them at the front end. Make sure that the clips are well soldered, thoroughly cleaned, and the insulating material carefully placed between them. When a detachable end bell is used, make sure that it is tight so as to keep the oil from working up through the joint into the winding.

DIPPING AND BAKING

The dipping and baking of armatures after they are wound has proved a great advantage, as it fills up all the cracks in the coils, increases the life of the insulation, and protects the winding from moisture. The main points to be watched in doing this work are to see that the armature is cleaned and dried before dipping, that it is well drained, and that the varnish is baked properly.

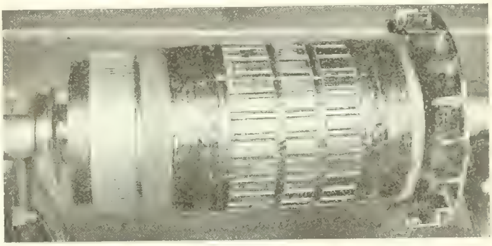

FIG. 6—COMPLETED ARMATURE

FINISHING

After dipping and baking, turn the commutator and apply the bands that were omitted. Undercut the commutator, as it helps commutation and flashing. Use a sharp cutter for this work, and see that all slivers of mica are removed from between the bars. Finish the completed armature by applying a protecting coat of air-drying insulating varnish.

A completed armature ready for assembling in the motor frame is shown in Fig. 6. It shows the bands and anchor clips, the undercutting of the commutator, the heavy braid over the hood and the commutator neck, and the insulation over the front mica V-ring.

TESTING

The armature should be tested for short-circuits and grounds to insure a first class product. Make tests during the winding, so as to catch any defects as they occur and avoid extra work that would be necessary if the armature failed after being completed. Give the armature a ground test after the coils are wound, after connecting, and when completed. If a running test is made, test the armature after the run and while hot. The first test should be higher than the final one required, and each test between cut down in value accordingly. Test the leads for cross wires before the top leads are connected to the commutator. Test the armature for short-circuits after it is connected and when completed.

When an epidemic of failures occur in the winding department or in service, analyze the conditions surrounding the failure and determine the cause. When motors are in service, a considerable length of time may be required to arrive at the cause, as failures are often cumulative and the exact reason may not be apparent. It is surprising what results can be obtained and how the mileage per motor failure can be increased, when each failure is carefully analyzed.

Foot Control of Safety Cars

As Exemplified by The Third Avenue Safety Cars in New York

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THE ADVENT of the safety car principle has made possible the safe operation of a public conveyance by one man.* A scheme of operating such cars which has made the work of the operator more nearly automatic is in successful use on the Third Avenue Railways of New York City. This control has many advantageous features, embodying safety appliances and simplicity of operation. Based on the successful operation of an experimental equipment, the Third Avenue Railways Company has equipped a number of its car with the foot control. These cars were formerly battery cars; and due to their being withdrawn from service, the idea was conceived of converting them to safety cars. As a result new trucks, new electrical equipment, and general re-enforcement of the car body was necessary. Fig. 1 shows the car equipped and ready for service.

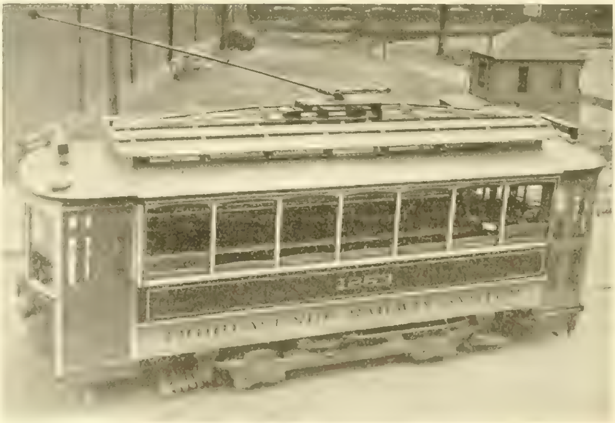

FIG. 1—FOOT CONTROL SAFETY CAR

The electrical equipment in general consists of two motors and automatic time control arranged to operate in conjunction with the foot control device. The automatic time control relieves the operator of the responsibility of notching the control to the running position, under all conditions of grade and load. The movement of the foot pedal is simple, there being only two positive movements necessary to start and stop the car. They are—full down position for power, up position for brake. An intermediate position corresponds to the lap position of the brake handle, with power off, permitting coasting. A further raising of the foot applies the brakes. Lifting the foot entirely from the lever, makes an emergency application of the brakes. The wide range of movement of the foot pedal permits very close graduation of the air valve.

The foot mechanism consists of a foot pedal, pivoted on a fulcrum support from the floor, with a foot pad on one end and a weight, in the form of a rod, on the other end. The weight extends up to about the level of the brake valve and is attached to a bell crank, which transfers the motion of the weight to the brake valve. By this means the brake valve is actuated by the foot. The bell crank center is mounted rigidly on a shaft, which is attached to a control drum, transferring the movement to the electrical control contacts. This gives a complete linkage of the foot device to the air brake and control circuits.

The door mechanism is interlocked with the controller, so that the car cannot be started with the door open, nor can the doors be opened while power is applied to the motors, or while the car is coasting. When the foot lever is allowed to rise to the emergency position, however, or whenever the power circuits are dead, as for example, when the trolley pole leaves the wire, the air pressure is exhausted from the door mechanism, so that the doors can be opened by hand, regardless of the position of the door operating button.

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*See articles on this subject in THE ELECTRIC JOURNAL by G. M. Woods, Oct., 1918, p. 300; N. H. Callard, Jr., Oct., 1919, p. 447, and E. A. Palmer, Oct., 1919, p. 426.

THE NEW SYSTEM OF CONTROL

The ideal type of automatic control for electric cars is one that will place the motors on their normal operating curve under all conditions of grade and load, without abuse to the equipment or discomfort to the passengers. Up to the present time, very little has been accomplished on automatic acceleration, which would be universal in its application. The functions of the automatic time control are almost identical with the much desired type of automatic control. In the design of this control, all conditions of railway service have been accounted for, and hence the system is universal in its application.

Perhaps one of the most attractive features of this control system is the method which is used to obtain the time element on automatic acceleration. The practice in the past to secure time element in the control has been the use of a current limit relay, to arrest the notching when a definite current value is reached and start it again when the current falls below a predetermined value. The use of this relay is limited to easy grades, smooth curves and no overloading. To overcome these objections, a motor driven sub-master controller is used, which is known as the sequence switch. Copper contacts on the drum are arranged to operate the contactors in accordance with the sequence chart shown in Fig. 5. The drum contacts engage with a set of steel control fingers mounted on an insulating base adjacent to the drum. A small bevel gear fastened to the drum shaft, engages with a second bevel gear fastened to a small shaft equipped with a worm drive, which is driven by a 1/12 hp motor. A small fuse and resistance tube are mounted on the base of the sequence switch. The fuse is connected in the lead which connects the main motor field to the sequence switch motor and is used as a protection against open circuit in the main motor field. The resistance tube is used to calibrate the speed of the motor.

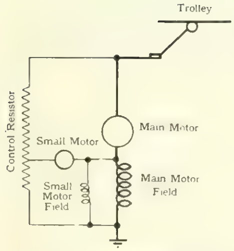

FIG. 2—FUNDAMENTAL CONNECTIONS FOR AUTOMATIC TIME ACCELERATION

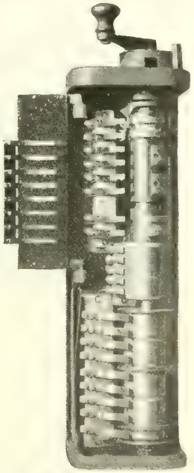

FIG. 3—SELECTOR SWITCH showing foot drum, control drum, and reverser.

The fundamental connections of the sequence switch are shown in Fig. 2. The field of the small motor is in parallel with the field of the main motor, and for this reason the current which passes through the field of the small motor is proportional to the current through the field of the main motor. The field strength of the small motor, therefore, is dependent on the load on the main motors. Increased field strength means decreased speed of the small motor, and consequently a decreased rate at which the copper contacts on the drum are moved under the fingers, producing an increased time between notches in the sequence chart. The inverse is true when there is a weak motor field. The armature of the small motor is also connected to the field of the main motor. Hence, any drop across the main motor field affects the voltage across the armature of the small motor, and for this reason the small motor armature speed is also regulated in accordance with the load on the main motor. This combination of connections gives both field and armature control over the small motor in accordance with the load on the main motors during the period of acceleration.

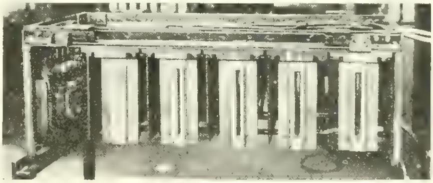

FIG. 4—SWITCH GROUP
Showing arc boxes and sequence relay.

The new type of automatic control consists of the following principal pieces of apparatus:—selector switch, switch group, sequence switch, control resistor, sequence relay, over-load trip and main resistor.

The selector switch, shown in Fig. 3, resembles a master controller and in some degree performs that function. This switch consists of a foot switch drum; a control drum, which establishes the first notch series position and full parallel position of the control; and a main reverse drum, which handles the main circuits and is used to reverse the fields of the main motor. The control and reverse drums are rigidly connected together.

The switch group, Fig. 4, consists of five magnetic switches, the overload trip and the sequence relay. The switches and relays are connected in the main and control circuits as shown in Fig. 5.

The sequence relay is an interlocking device which carries three simple contacts and is connected in the circuit as shown in Fig. 5. The overload trip is a standard piece of apparatus commonly used with all remote control equipments.

The switch group and the main resistor are the only parts of the control which are mounted underneath the car. The switch group is placed between the axles and the main resistor on the outside. The selector switch is mounted at the usual location of the master controller on the platform. The sequence switch and the control resistor are mounted at convenient places underneath the seats.

To operate the car after the main switch and control switch have been closed, the selector switch is placed on the first or switching notch in the forward position, assuming that the car is to run forward. The foot pedal is then depressed to the full down or "on" position, which will close the foot switch in the top of the selector switch. Then the LS_1 switch will come in, giving the first notch in series. The selector switch should then be thrown to full series position. The sequence switch drum moves in one direction only and stops immediately when the foot pedal is raised during the period of acceleration. When the foot pedal is again pushed down to the "on" position, the sequence switch drum moves around at a high rate of speed to the first position, all switches except the LS_1 being held out, in the meantime, by the sequence relay. The sequence relay picks up at the first position and applies normal voltage to the small motor. The control is then notched up until the drum is stopped by the series or parallel finger, depending on the position of the selector switch handle.

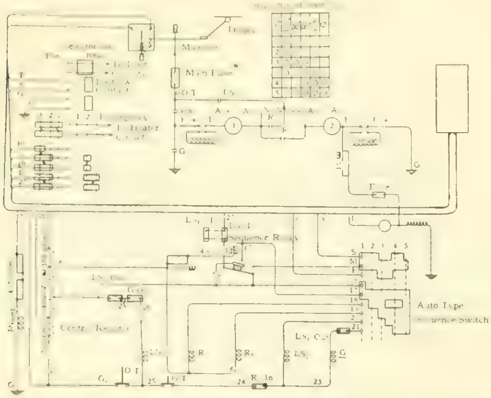

FIG. 5 — MAIN AND CONTROL SCHEMATIC DIAGRAM

After full series running of the motor is obtained, the motor selector switch is thrown to the full parallel or No. 3 position. This step can also be obtained with the foot switch closed. The sequence switch motor then starts up again at normal operating speed, bringing in the LS_2 switch, dropping out the R_1 switch and the LS_1 switch, and bringing in the G switch for the first parallel notch. The drum of the sequence switch will keep on going at a rate of speed determined by the grade and curve conditions, bringing in the R_1 switch for the full parallel notch, at which point the sequence switch drum will stop.

Since the acceleration is entirely automatic, for normal operation the selector switch handle can be left in the full parallel or other desired position, and the car started and stopped solely by the use of the foot lever. The car will then accelerate automatically and continue to run at the desired speed until either the foot lever or the selector switch handle is moved. It may be necessary, during times of blocked traffic, to keep the selector switch on the switching or No. 1 notch.

For tangent level track conditions, the sequence drum requires approximately seven seconds for a complete cycle. This time, for the same conditions, can only be changed by changing the inherent characteristics of the switch by means of the resistance tubes in the motor field circuit as shown in Fig. 5.

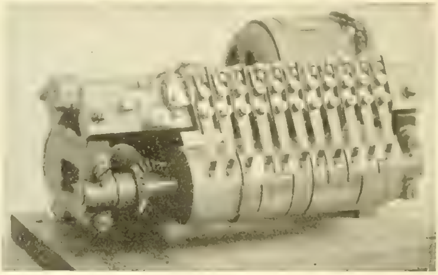

FIG. 6 — SEQUENCE SWITCH AND AUTOMATIC TIME ACCELERATING DEVICE

In the reverse direction of running, there are the switching and full series notches, and the emergency braking notch. To get from the forward to the reverse position, it is necessary to release or open the foot switch, as it is interlocked with the shaft of the selector switch. This also holds true for the emergency position. To obtain emergency braking the foot switch must be opened and the handle of the selector switch thrown to the emergency position. This disconnects the line voltage and connects the motors in series through all the resistance, and the car is reduced in speed by the dynamic action of the motors. The selector switch handle automatically locks itself in this emergency position, requiring the operator to use both hands to return the handle to its off position.

The new ideas involved in this type of control are the use of the foot mechanism, interconnecting the motor sequence switch with the main motor circuits, so as to produce automatic time acceleration, and the arrangement of the main circuits and main resistor so as to obtain five notches on the control with the use of only five main switches.

Some Points on Dipping and Baking of Railway Motors

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DIPPING AND BAKING motors that have been in service will give renewed life to the insulation. The varnish will fill up cracks and pores and present a clean glossy surface to which dirt does not cling and which will shed and is impervious to water. Dipping of coils alone will not give this result because the manipulation of the coils during winding will usually crack the baked coating. The completely wound unit, armature or field, should be given the treatment.

Some advantages of dipping and baking the complete unit are as follows:—

1—The coils are cemented securely into the slots by the varnish and are therefore less subject to individual vibration.

2—All cracks and pores are filled up, thereby preventing deposition of dirt or moisture.

3—Loose punchings or laminations are sealed and vibrations prevented.

4—The armature is completely covered with a rust preventing coat. Rust is a conductor of electricity and sometimes finds its way into the windings.

5—A smooth surface is formed which prevents creepage.

6—Any insulation which may have been bruised or cracked during handling or winding is restored to good condition.

7—The solvent of the varnish being benzine, all oil or grease is thoroughly cleaned from the armature by dipping in this varnish.

A striking example of what can be accomplished in the way of reducing failures by means of dipping and baking is shown by Fig. 1. These curves show car-miles per armature and field failure plotted against years. It will be noted that a decided improvement starts in the year 1908, at which time the master mechanic in charge of this property instituted a systematic schedule of dipping and baking his motors. It is significant that street railways operating in the ten largest cities in the United States dip and bake their motors. Also nearly all electrified steam railroads in the United States follow the same practice.

In general, all armatures or fields should be cleaned by blowing out with compressed air and in cases where the air does not seem sufficient, they should be cleaned with gasoline. They should then be dried by baking and dipped while hot. No general set of instructions can be given to cover the dipping and baking of armatures without incorporating much information which would be of little use to the user of one particular size or type of motor. That is, in dipping and baking large motors, the procedure to be followed differs from that to be followed by the user of small motors. And even in the case of small motors, the procedure is not the same if the construction of the armature differs in certain details. Different localities and service conditions require different methods of dipping and baking. However, the fundamental principles of the operation are the same for all sizes and types of construction, and all localities and conditions of service. The procedures differ only in the method of immersion and draining, the temperature and length of time of baking, and the number of dips and bakes.

There have been cases where the dipping and baking has been done using the wrong kind of varnish. As a result the coils were not filled but merely coated with a hard glossy coat. This was all right so far as it went, but for the same expenditure, a treatment could have been given which would impregnate as well as coat, consequently this operator was not getting the most for his money. In another case, the operator rolled the armatures in a large pan containing the varnish and then baked them. No cleaning or drying of the armatures was done before the rolling, consequently all the dirt and moisture was sealed into these armatures.

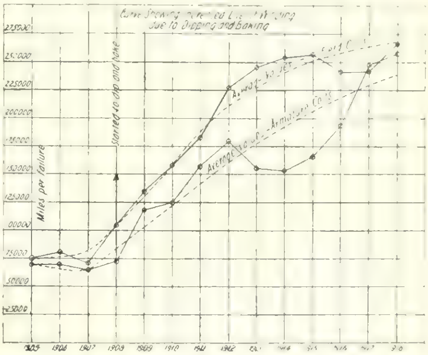

FIG. 1—INCREASED LIFE OF WINDINGS DUE TO DIPPING AND BAKING

While there is nothing difficult or intricate about dipping and baking, it is very easy to do improperly. Therefore, anyone planning to do dipping and baking should write to the manufacturer of his motors for proper instructions as to the correct procedure in the case of his particular equipment.

Inspection and Maintenance of Direct-Current Car Control

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THE SERVICE which may be expected of any equipment is measured directly by the amount of care which is exercised in its maintenance. At present, the tendency is to reduce maintenance, on account of the high cost and scarcity of labor, together with the difficulty of obtaining repair parts. But to neglect this important phase of such an important industry as the electric railway violates sound business principles.

Few of the electric railways of this country keep accurate maintenance records. It is hard for those who do not keep such records to determine the exact financial return which is effected by keeping equipments in the best of condition. If every man responsible for the upkeep of equipments realized definitely the waste entailed by poor maintenance, equipments would be kept in better condition.

The fundamentals to be considered in the operation of railway equipment are:—

> *1*—To keep the cars on the road. It is only when cars are in revenue service that they pay dividends on the investment.
>
> *2*—To forestall trouble on the road by making repairs before failure can result.
>
> *3*—To maintain all parts in such condition that the depreciation is a minimum.

The exact amount of work necessary to keep the equipments up to the mark is hard to determine. For this reason, every master mechanic must study his individual conditions, as these vary with service, class of motormen, class of labor, accessibility of equipment, climate, and shop facilities. It is obvious though, that when the apparatus is in first class shape, the labor required to keep it in this condition will be a minimum; therefore, the first step toward economical maintenance is to get the equipments into the best of condition.

A well stocked supply room is a necessity, in view of long deliveries and shipping troubles. The investment in such material, even at the present prices, is more than offset by having repair material on hand when needed. There is always the danger of extravagance under this condition but a simple system of checking out material and salvaging worn parts will curb this tendency.

Control parts are often manufactured in the operating company's own shops. This is satisfactory for emergency work, but is not good practice in general. Grades of material and workmanship are generally inferior to those of parts manufactured by established manufacturing companies and the cost, logically, must be higher when made in small quantities than when made in quantities by a company whose business depends upon manufacturing well and at a minimum cost, which necessitates adequate tool equipment. A number of cases have been brought to light where the operating company's records have apparently shown a saving by manufacturing some of their own spare parts, but a detailed cost study revealed the fact that all of the costs which were legitimately chargeable to manufacturing were not included.

In the maintenance of equipment, a definite inspection program should be rigidly followed, this program being based either on car mileage or time. Two classes of inspection should be scheduled, namely:—

> *Light Inspection*— Periodic inspection should be made of all wearing and burning parts, lubricating, tightening up, replacing contacts, battery inspection, and similar minor repairs, with sufficient frequency to insure against trouble on the road. A few hours in the barn should be all that is necessary to make such an inspection.
>
> *Heavy Inspection*—Every fourth or fifth inspection period should be made the occasion of a very thorough examination of all parts of the equipment. Covers should all be removed, all parts opened up and examined, dust and dirt cleaned out, insulating surfaces all wiped off and shellaced, if not smooth. Worn parts which are difficult to replace should be taken care of at this inspection rather than at light inspections if permissible to let them run that long.

A number of properties, especially the large ones, such as steam roads, subways and elevated railways, use a card for checking the inspection. As soon as the car is brought on to the inspection tracks a card is inserted in a metal frame and hung at one end of the car, listing the various items to be inspected. Each man after inspecting his assigned portion of the equipment, signs and dates the corresponding items on the inspection tag. These inspection cards are kept on file and in case of trouble, the responsibility for the trouble can be definitely placed. For heavy inspection the color of the card is usually changed, rather than the form. Thus, if the regular inspection tag is white, a blue card could be used to indicate a heavy inspection. In case a car came in for some particular trouble a red card might be used to indicate that only the items checked off were to be inspected and repaired. This card system forms a valuable check on the men and insures that none of the equipment is overlooked. It is surprising that more of the smaller roads do not make use of so simple a system of checking the inspections.

Heavy overhauling must be made periodically in order to keep an equipment from depreciating unnecessarily. These overhauls are required because there is always wear and deterioration which cannot be cared for even by careful heavy inspections. The period between such heavy overhauls varies considerably with operating conditions, but is generally from one to two years. By careful planning, the work in the shops may often be balanced so that a minimum number of men may be employed continuously and at the highest efficiency. Equipments which are subjected to the most severe winter conditions are preferably overhauled during the late summer or fall, while those used for heavy summer traffic to resorts and amusement parks should be taken care of during the winter or spring.

In overhauling an equipment all apparatus should be taken down and taken apart, whether it appears to need attention or not. It is often found that wear has occurred in unsuspected places, that dirt has accumulated on insulation in places where it cannot be seen, and that loosening has occurred due to the incessant jarring. By taking the apparatus apart and out into the daylight a much more thorough examination may be made.

The maintenance of a control equipment involves close attention to details. Each piece of apparatus is constructed for a different purpose and its construction requires that different items be watched. The most important parts to be maintained in a drum controller are the fingers and segments, while in a circuit breaker the tripping mechanism should be most carefully watched. Numerous articles have appeared describing methods of caring for individual pieces of equipment and it is impossible to include the entire subject matter here for the lack of space. However, a general resume will be made giving some of the most important considerations.

DRUM CONTROL

First consider the drum control equipment in its simplest form. Such an equipment consists of trolleys, lightning arresters, fuse box, circuit breaker, drum controllers and resistor.

Trolleys—Wear of the wheel and wheel bearing are the greatest sources of trolley trouble. An arcing wheel means not only more rapid wheel wear but damage to the trolley wire itself, which is often overlooked by the equipment maintenance men because an entirely different department has charge of the overhead. Worn wheels and bushings, crooked poles, and worn bearings in the base will cause wheels to leave the wire, with the possibility of damage to the overhead equipment and to the trolley pole. Keep the wheels, wheel bearings, base bearings, rope and retriever in good condition —it will pay in the long run.

Lightning Arresters—It is difficult to tell whether an arrester is properly performing its duties or not. An absence of trouble gives the only indication, and such absence must be based on records of previous years. Even with arresters in the best of condition there is no absolute protection from a direct lightning stroke. For general inspection purposes, however, a visual inspection must be relied upon, for the average road does not have the necessary equipment to make a high-voltage, high-frequency test. See that the wire connecting to the trolley and also the ground wire are well connected at all points; that there are the minimum number of bends in these wires and that all necessary bends have a large radius; that all parts are clean and free from dust; and that spark gaps (if part of the arrester) are properly set and clean. With an electrolytic type of arrester, even more attention must be given. The electrolyte must be properly maintained and must be kept from freezing. It is customary to remove this type of arrester from cars during the winter months where freezing is likely to occur.

Fuse Box—Where a fuse box is used with drum control equipment, the inspector must see that all parts are clean, that no creepage is occuring to ground, and that the fuse is in good condition and clamped tightly.

Circuit Breakers—In order to afford the maximum protection to an equipment, the circuit breakers must be kept in the best of operating condition and the setting should be kept at the predetermined point. This point should be as low as operating conditions will permit and should never be more than 200 percent of the total motor current (hour rating) passing through the breaker. It will be found that a number of motormen consistently try to increase breaker settings, so that frequent checks must be made.

Blowout coils should be examined for evidence of heating; all parts examined to detect wear, chafing or looseness; contacts trimmed up (or replaced if badly burned); arc chutes repaired with arc cement or replaced if necessary; all parts, especially the insulation, cleaned; and a few drops of oil applied at wearing points to prevent rusting, care being taken to see that no surplus oil is left to gather dirt.

It is often difficult to check the setting of a circuit breaker while in its regular position on the car. It is most desirable to check in this way, if possible, but if not, the circuit breaker should be removed from the car and checked at the bench.*

Drum Controller—The extensive use of the drum type of controller for street railway work makes this the most familiar of all pieces of control equipment. Its maintenance is simple and will require no detailed comments, as the chief maintenance problems are to keep the finger tension and lift correct and to keep the contacts and contact plates smooth and well lubricated. The finger tension should be about eight pounds per inch width (thus a one-half inch finger should have a tension of 4 lbs.) and the lift should be between 1/16 and 3/16 inch. Care should be taken to see that lubricant is not applied too heavily and all excess is wiped off the edges of fingers and segments.

Resistors—In general, resistors require very little attention. It is well, however, to have a definite inspection program for this apparatus and not trust to a casual glance. The main sources of trouble lie in destruction of insulation, broken grids, and overheated grids. The first of these can usually be anticipated and steps taken to correct trouble. The installation of splash shields, if carefully placed, will do a great deal toward the elimination of insulation breakdowns, which generally result from deposits of dirt and salt encrustations. In one city, where a great deal of salt is used during the winter to keep the track switches open, it is found necessary to provide eighteen inches of creepage distance along the oak supporting timbers from the resistor frames to grounded portions of the car body.

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*A convenient bench testing outfit is shown in Fig. 1, Railway Operating Data for Sept. 1917, p. 369.

Broken grids are usually detected by running a hammer handle along the sides of the grids and detecting broken ones by sound.

Overheating of resistors in service will often result in sagging of the grids. This may cause grid breakage or the convolutions may come together which reduces the resistance value. As the sagging generally occurs in the middle of the grids, where the heat is not radiated as fast as at the edges, it is not easily detected. Such cases usually require replacement, and if they occur frequently, the method of operation should be checked and the capacity of the resistor increased if necessary.

Keep resistors and resistor insulation clean and the tie rods tight and they will operate with a minimum of trouble.

LINE SWITCH EQUIPMENTS

The addition of a line switch to a drum control equipment does not materially alter its inspection program. The line switch generally replaces the circuit breakers and is mounted under the car, being operated by means of a set of control contacts at the controller. The inspection and maintenance differ from the drum control equipment only by the removal of the circuit breakers and the addition of these control contacts, the line switch, and control switches. With the electropneumatically operated line switch are included the pneumatic details, such as reducing valve, air strainer and reservoir. The maintenance of the unit switch (the line switch is a unit switch) is described in the following text.

REMOTE CONTROL OR MULTIPLE-UNIT EQUIPMENTS

The widespread use of this type of equipment has demonstrated that its maintenance is scarcely more difficult than that of the drum type of equipment. While the pieces of apparatus appear more intricate and require a better understanding of their purpose and operation, the average maintenance man has progressed in the last decade and is easily capable of caring for them. A simple HL control equipment consists of trolleys, lightning arrester, fuse box, main switch, control box, main resistor, control switches, master controllers, junction boxes, control resistor and pneumatic details. The control box includes eight unit switches, the overload relay, reverser, and cutout switch. For larger equipments, two additional unit switches are required and these are added in a separate frame, known as the line switch. For multiple car operation it is only necessary to add receptacles and jumpers for carrying the control circuits from car to car, although details are sometimes added for carrying the bus line between cars.

The details comprising the HL equipment have been given, as this is the simplest remote control system now available for the average car. Special features, such as means for operating in train with other special control equipments, the use of battery control circuits, automatic acceleration, and other such features, will, in general, be covered by the maintenance methods described for this standard equipment.

The trolleys, lightning arrester, fuse box, and resistor should be inspected and maintained as described under "Drum Controller".

The Main Switch requires very little attention, but should not be neglected on account of it. The jaws should be kept clean and should fit the knife blade well. All dust should be removed and parts inspected for heating.

The Unit Switches, mounted in the control box, will be found to require the most attention, because they are subjected to the heaviest duty. The contacts should be lubricated lightly at each inspection with a thin coating of vaseline, taking care not to get it on the arc sides or other places where it will gather dust, dirt or copper particles. Worn contacts should be replaced. Arc sides should be examined, cleaned and filled with arc cement if any deep burns appear. Bearing pins should be watched for signs of cutting, which may be detected by the appearance of filings deposited on the piston insulator. Interlocks should be examined for wear and the finger tension should be kept between three and five pounds. A convenient method of determining finger pressure is by the use of an accurate spring scale fitted with a stirrup to fit over the bearing point of the interlock finger.

At heavy inspection periods, the cylinders and bearing pins should be lubricated with a few drops of HL oil (a good grade of engine oil will be satisfactory if HL oil is not available), the switch studs should be examined for heating and tightened, all insulating surfaces wiped clean, and magnet valves should be gauged and adjusted to have the correct air gaps (the equipment manufacturer will supply the data for gauging).

Reversers—The drum type of reverser is a source of considerable trouble, yet its simplicity and relatively low cost recommends its use in place of unit switches, four of which would be required per motor if the motors were to be reversed by means of switches. But if the proper attention is given the drum type reverser, its troubles may be minimized.

The chief cause of reverser burnouts lies in "bucking" the motors and then throwing the reverser to the running position before the generated current has died out. As the reverser opens the motor circuits, in throwing from one position to the other, the flash resulting from opening this generated current causes large volumes of gas to be released within the reverser covers. This hot gas is a very good conductor and allows further flashovers between other contact plates and fingers, with serious burns as a result.

Motormen buck the motors most frequently during very cold weather, when the air brakes freeze up, and for this reason reversers should be most carefully watched during extremely cold weather. If beads appear at the edges of contact plates or on fingers, they should be filed off carefully. Charred surfaces of the drum between contact plates should be scraped and shellaced and all parts be kept free from dust and copper cuttings.

A recent improvement in reversers consists of placing flash barriers around the drums. These barriers prevent the gases caused by flashing from forming a direct path to adjacent contacts and thus eliminate a large part of the trouble. In placing contact plates on a drum, great care must be taken to see that they bear the correct relation to the other segments. It is essential that the interlock contacts be correctly placed, as a variation of 1/16 of an inch may cause the reverser to burn. In replacing such contacts it is necessary that the manufacturer's drawing be followed closely.

Master Controllers—The maintenance of a master controller is not difficult, but there are a few points which deserve careful attention. The fingers and contact segments should be watched and their pressure and lift kept up to standard. Too great a lift may result in stubbed fingers and too light a pressure cause loss of contact, especially with a drum which is slightly eccentric. Contacts should be watched carefully for wear and if the ends burn back, they should be built out to make contact at the proper point. A forcible example of this was recently brought to light on one property, where one of the switches would burn very rapidly and for no apparent reason, as the arcing duty was supposed to be very light. It was found upon investigation that the master controller had worn back so far that during transition from series to parallel this switch would open the circuit momentarily. Building out the controller segment entirely eliminated the trouble.

Pneumatic Details—None of the other details of a remote control equipment offer any special maintenance problems except the pneumatic details. If these are not properly installed and maintained, however, the whole equipment may be affected. When an equipment is new it will be found that scale and dirt are dislodged from the inside of pipes and find their way into valves, causing leaks. It is best practice to blow out the piping thoroughly after the equipment has been in operation for a month or two, by disconnecting at various places. A number of properties also provide a receptacle to catch scale and dirt at the lower end of vertical runs of pipe. The amount of dirt collected amply justifies their installation.

Water and oil carried over from the compressor are constant sources of trouble, especially in winter, when freezing of the moisture causes sluggish pistons and valves to freeze. Careful installation of the piping system, so that water drains away from the control apparatus, together with an adequate cooling system ahead of the control reservoir will eliminate some of this trouble. Reducing valves are another source of trouble unless carefully watched. The reducing valve setting should be checked at each heavy inspection period by the use of an inspector's gauge.

A careful study of the whole maintenance problem discloses the fact that the best results are obtained by the man who knows the equipment most thoroughly, and who spares no pains in repairing the details. The motto of the maintenance man should be "Know Your Equipment, Watch the Details, and Keep Your Covers Tight."

Haul Freight the Electric Way

By Use of Standard Freight Equipment

E. D. LYNCH
Railway Sales Dept.,
Westinghouse Electric & Mfg. Company

THE SLOW PROGRESS which freight haulage on electric railways has made in these times when the need for increased transportation facilities is so obvious, is positive evidence that the electric railway industry is lacking in commercialism. The possibilities of freight haulage by the electric lines of the country are hard to appreciate, since so few roads have made more than a feeble attempt to develop this branch of the railroad business. The transportation of freight by every possible method is a national necessity, and is essential to the growth and progress of each individual community. With the expansion of local industries there must be an enlargement of transportation facilities. The result of this natural progress has increased the size of the steam roads until their magnitude has exceeded even the most optimistic predictions of their original promotors. In other words, freight haulage made America's steam roads. It represents their main source of revenue and always will. It is, however, impossible for the existing steam roads to meet the ever-increasing community demand for additional transportation service without extensions and added equipment. It is needless to say that unless other facilities are employed, ultimate expansion of the steam roads will result.

That the existing rural freight transportation facilities are inadequate is forcibly indicated by the steady increase of auto-truck lines. They have become a prominent factor in our transportation system. On account of the hesitancy of the electric railways to adopt freight haulage, they now must face auto-truck competition in many places where the auto-truck could have served as an adjunct to the electric railway. The success of such a combination is exemplified by a few of the country's more progressive electric railways. One of these—The Milwaukee Electric Railway & Light Company—has created auto-truck feeder service reaching in some cases 60 miles from its terminals, serving, farming and manufacturing districts, otherwise far remote from neighboring towns and cities.

Every electric line of any importance has freight possibilities, which could be handled in addition to its regular passenger service. Where people travel, a demand naturally exists for the moving of freight. With so many indications of a real paying business in evidence, little additional encouragement should be required to induce every electric railway to engage in freight haulage, especially when every possible opportunity for an increase in revenue is so vital.

A number of electric railways have built up intensified freight systems and the methods employed by these roads and their experience in the building up of their business are available to all. Among the prominent lines which have been developing their freight opportunities are—

Pacific Electric
Utah Idaho Central
Salt Lake & Utah
Detroit United
Waterloo, Cedar Falls & Northern
Northern Ohio Traction
Michigan Railways

Aside from the necessity of system, the confidence of the public, continuity of service and other requisites for rapid development of freight haulage, the equipment is an exceedingly important factor in placing the freight business on a sound and profitable basis. It is the manufacturer's function to supply reliable and appropriate equipment. Co-operation between operator and manufacturer is, therefore, necessary to extend the designs of suitable apparatus to cover all freight requirements. Terminal and warehouse facilities, tracks and feeder systems may be adequate to handle the business effectively, while the rolling stock may be expensive, unreliable and unsuitable. For example, it would be a mistake to expect material success from the use of antiquated, under-capacity motors applied to old wood baggage cars converted from passenger service. The average electric railway considers that any equipment which has passed beyond its usefulness for passenger service is still good enough for work-cars, sprinklers, sweepers, etc. Satisfaction, of course, depends entirely on circumstances and conditions, but certainly the reliability of such service equipment will be no greater than it was before the transfer from revenue service. Such re-arrangements may meet with approval in many instances, but it is a mistake to carry discarded equipment into freight haulage, except where careful analysis is made. Equipment selected as revenue builders should not only be efficient but permanent in their reliability and adequacy. Revenue will not then have to be used for maintenance, but can be spent for increased equipment and facilities as the business grows. The entire problem must be handled as a business enterprise, where efficiency and economy, with the maximum rate of healthy progress, is the direct aim.

Package freight or express is usually the ground floor of freight business on most electric railways. Beginning at the bottom is a step in the right direction, and encouragement would certainly be created for the industry if even this lowly start were made by all roads. On a large number of lines, however, the beginning could be made at a more advanced stage. Nearly every railway company has use for at least one electric locomotive for handling construction work and the many ordinary maintenance supplies used every day. One or two engines would replace many make-shift motor-driven work cars and at the same time would serve to inaugurate night time freight train service between towns served by the line. Car load movement at night, when the power demand for passenger service is low, would entail no change in the power distributing system. Fast package freight could be maintained during the day time in conjunction with the regular passenger train service. In other words, little additional rolling stock would be required by most of our electric lines, to make a fairly advanced participation into freight haulage.

With the start made and the will to succeed, together with systematic, commercial advertising, the majority of electric lines would be able to render better all-year-round freight service to their respective communities than either the auto-truck or the steam roads. With reliable service established, every farmer, merchant and townsman along the line will become a customer, where they now are either deprived of many necessities or are forced to use teams or auto-trucks, which require both time and investment. If such private modes of transportation can be eliminated by a new and cheaper system, economy alone will attract patronage.

The ideal freight system on electric railways would include freight train service handled by standard electric locomotives of about 25, 40, 50, and 60 tons weight. Such engines will haul trains of from ten to thirty standard steam road freight cars at moderate speeds on level tangent track. Manufacturers have developed these sizes of locomotives with motors and control especially designed for electric railway interurban freight service. The adoption of these established standards without injecting special features not only assists materially in the development of a wider range of locomotive sizes, but helps maintain low first costs for both engines and repairs. Standard electric locomotives are not in the experimental stage, for they have been operating successfully as real revenue builders for more than ten years. They are the result of years of experience in both steam and electric locomotive building and their merits have been proved in actual freight and passenger service.

Many inherent advantages attend the use of either locomotives or package freight, but to have the package type of car approach locomotive reliability in train service, reinforcement of the car body for heavy pulling and buffing is necessary. The motor and control equipment must also be arranged for locomotive operation by installing standard locomotive apparatus throughout.

Locomotive train service, as compared to package freight car operation, has many superior points, among which are:—

Lower first cost.
Fewer repairs.
Fewer men or power units to maintain
Fewer crews required.
Fewer units represent a saving in power.
Locomotives are designed to stand strains and stresses and rough handling in train service.
Fewer but heavier trains lessen congestion.
The use of non-motor trail cars lessens investment while unloading

Many arguments have been presented in favor of freight transportation for electric railways, but one of the most convincing is the fact that steam road progress is due to freight, and that to those electric lines who have it developed, freight revenue has been a life saver during the recent railway crisis.

"Haul Freight" should become the slogan of the electric railways, because prolonged delay will simply mean increased auto-truck and steam road competition. Now is the time to participate if the electric railways ever expect to obtain their share of this business.

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

To receive prompt attention a self-addressed, stamped envelope should accompany each query. All data necessary for a complete understanding of the problem should be furnished. A personal reply is mailed to each questioner as soon as the necessary information is available; however, as each queston is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply.

1916—ELECTRICAL ENERGY REQUIRED FOR HEATING BUILDINGS—What factors must be taken into consideration to determine the electrical energy required to heat a room or a building.
F.H. (W.VA.)

To determine the electrical energy necessary to heat a room or building, many factors must be taken into consideration. Heat is lost (a) by transmission through walls, floor, and ceiling (see Table I), and (b) through air necessary for ventilation (see Table II). The exposure of the building must also be considered.

TABLE I—WATTS LOST BY RADIATION PER SQUARE FOOT OF SURFACE PER DEGREES F. DIFFERENCE IN TEMPERATURE

Radiating Surface	Watts
24-inch brick wall	0.0575
12-inch brick wall	0.0925
9-inch brick wall	0.1350
4-inch brick wall	0.1930
Wooden Flooring	0.0305
Wooden ceiling	0.0245
Fire-proof flooring	0.0360
Fire-proof ceiling	0.0425
Single window	0.355
Single skylight	0.300
Double window	0.170
Double skylight	0.185
Door (65 percent wood—35 per cent glass	0.170
Door, plain	0.120
Wood Partition—1-inch thick	0.120

These co-efficients, for latitudes approximately that of Pittsburgh, will be increased as follows:—

10 percent for northern and windy exposure.

10 percent where building is heated during day time only, and building is not exposed.

30 percent where building is heated during day time only, and location is an exposed one.

50 percent where the building is heated intermittently during the winter months.

TABLE II—AIR REQUIRED FOR VENTILATION OF ROOMS

Service	Cubic Feet of Air Per Hour
Hospitals	3 600 per single bed
Legislature assembly halls	3 600 per seat
Barracks, bedrooms and workshops	[illegible] per person
Schools and churches	[illegible] per person
Theatres and ordinary halls	2 000 per seat
Office rooms	[illegible] per person
Dining rooms	[illegible] per person
Homes	Once per hour

A quicker method of determining approximately the amount of heat necessary to maintain the temperature of a room is given in the following formula:

$$\left(\frac{W}{4}+G+\frac{C}{55}\right)=\frac{T}{3.4}=\text{heat losses in watts}$$

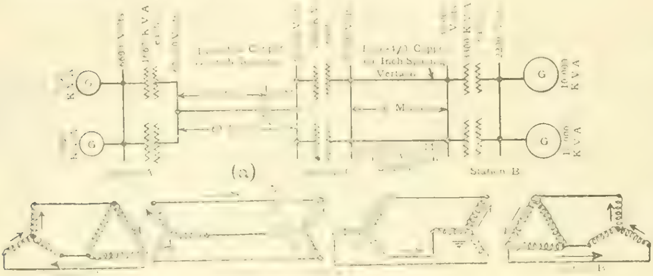
Where
W = exposed wall surface in sq. ft.
G = exposed glass surface in sq. ft.
C = contents in cubic ft.
T = difference between inside and outside temperature in degrees F. This formula assumes that the building is of good construction, with fairly thick walls, tight-fitting doors and windows and no unusual conditions, such as exposure to high winds, etc. It is an approximation only, for preliminary estimates, and not to be considered accurate for all cases. In all calculations of the heat necessary to obtain a certain result, the character of the installation must be considered. For instance in a small store where the doors are opened often, an additional allowance should be made. In a home the loss from this may be neglected. The lowest outside temperature on record should be used in these calculations. Example—Office 15 by 15 by [illegible] feet—located at the northwest corner on the third floor of a four-story warehouse. The building has 12-inch brick walls, floors of fire-proof construction, two windows, each 18 square feet, one door 3 by 7 feet, a one-inch wooden partition. Temperature of office to be 70 degrees F., balance of building 40 degrees F., outside zero degrees F. Air supply 4000 cubic feet per hour. Then according to the above conditions:

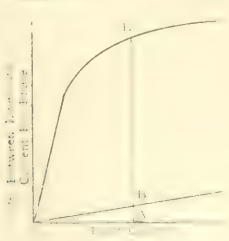
Exposed wall . . . 264 sq. ft. by 0.0925 by 70 = 1710 + 10 percent = 1880
Exposed glass . . . 36 sq. ft. by 0.355 by 70 = [illegible] + 10 percent = 990
Interior partition . . . . 300 sq. ft. by 0.12 by 30 = 1080
Ceiling . . . . . . 225 sq. ft. by 0.0425 by 30 = 290
Floor . . . . 225 sq. ft. by 0.036 by 30 = 240
Air 4000 cu. ft. by 0.0054 by 70 = 1510

Total Watts 5990

1917—CIRCUIT BREAKER CAPACITY—Figs. (a) and (b) show two generating stations 90 miles apart with an intermediate transformer station. Station *A* has two 5000 kv-a, three-phase, 50 cycle, 6600 volt, water wheel driven generators with a synchronous reactance of 80 percent and a leakage reactance of 20 percent. It has two banks of 1667 kv-a, single-phase transformers, connected delta star with grounded neutral to transform from 6600 to 60 000 volts. Station *B* has two 10 000 kv-a, three-phase, 50 cycle, 2200 volt steam turbine generators, having a synchronous reactance of [illegible] percent and a 10 percent leakage reactance. It has [illegible]

[illegible] with [illegible] connected 2200 volts delta to 30 000 volts star with grounded neutral. Station *C* contains two banks of 1500 kv-a single-phase transformers of 6.5 percent reactance connected star on both sides with grounded neutral to transform from 30 000 to 60 000 volts. The lines from *A* to *C* are of No. 0000 stranded copper with 72 inches triangular spacing. One line from *B* to *C* is of No. 0000 stranded copper spaced 60 inches apart in a vertical plane; the second line is of 300 000 circ. mils stranded aluminum, spaced 60 inches apart in a vertical plane. (1) Explain meaning, method of determination by tests and application of terms—"synchronous reactance" and "leakage reactance" as given above. (2) What would the line current be at station *A* and *B* for single-phase ground (no ground resistance considered) under conditions as follows:— (a) Ground at point *X*, [illegible] miles from station *A* when line *A-C* was open at station *C* and both generators were on line at station *A* and carrying no load? Full load. (b) Ground at point *X*, 50 miles from station *A* and 10 miles from station *C*, when all generators are on the line and fully loaded? When one generator only is on at station *B* and one *B-C* line is out of service? (3) Please give formula used and method of application so that other similar combinations may be calculated using other generators, transformers and lines. This information is to determine settings of switches and what current they may be called upon to break.





FIGS. 1917 (a), (b) and (c)

Leakage reactance—The load current in flowing through the armature conductors sets up a local magnetic flux which interlinks with the armature conductors, producing inductance. This inductance is called the armature leakage or inherent inductance. The leakage reactance drop at full load is generally expressed in terms of full load terminal volts. To calculate the leakage reactance in ohms, use the following formula:

Leakage reactance in ohms per phase = $\frac{p E}{100 I}$

Where
p = Percent leakage reactance drop.
E = Volts per phase.
I = Full load current per phase.

Example:—Consider the 5000 kv-a generator in [illegible] star connected:—

Full load current per phase

$$= \frac{5000 \times 1000}{1.73 \times 6600} = 438 \textit{ amperes.}$$

$$\textit{Volts per phase} = \frac{6600}{1.73} = 3810 \textit{ volts.}$$

Leakage reactance per phase

$$= \frac{20 \times 3810}{100 \times 438} = 1.74 \textit{ ohms}$$

At present there is no convenient method of determining by test the leakage reactance of alternating-current generators. It can be calculated more or less accurately from the dimensions of the machine and can be determined from results of oscillograph tests on short-circuit.

Short-circuit ratio or synchronous reactance of a generator is the equivalent reactance which would produce the same effect as the armature leakage reactance and armature reaction combined. Synchronous reactance can be determined by calculations from the open-circuit and short-circuit characteristic curve as shown in Fig. (c). If in Fig. (c) *OE* = open circuit characteristic, i. e., no-load volts between lines plotted against field current and *OB* = short-circuit characteristic, i. e., armature current per phase plotted against field current, then *OA* = field current to give *AE* the normal voltage between lines and *AB* = armature current corresponding to field current *OA*.

$$\textit{Synchronous impedance} = \frac{AE}{1.73 \times AB} = Z$$

$$\textit{Synchronous reactance} = \sqrt{Z^2 - R^2}$$

Where R = resistance per phase.

(2a) For a 5000 kv-a, 6600 volt, three-phase, 50 cycle generator having twenty percent reactance.

Full load current per phase

$$= \frac{5000 \times 1000}{1.73 \times 6600} = 438 \textit{ amperes}$$

$$\textit{Generator reactance} = \frac{\frac{20}{100} \times \frac{6600}{1.73}}{438} = 1.74$$

[illegible] 1667 kv-a, single-phase, [illegible] to 6600 star eight percent reactance transformer:—

Full-load current per transformer

$$= \frac{1667 \times 1000}{6600} = 253 \textit{ amperes.}$$

Reactance per phase

$$= \frac{\frac{8}{100} \times 6600}{253} = 2.08.$$

The line *AC* of 4/0 copper, 72 inch spacing, has a reactance per mile of line at 50 cycles of 0.605 ohms. To calculate the equivalent reactance of ten miles of line reduced to generator voltage, proceed as follows:—

Reactance for 10 miles = 0.605 × 10 = 6.05 *ohms.*

$$\textit{Ratio of voltages} = \frac{\frac{66\,000}{1.73}}{6000} = 5.27.$$

$$\textit{Equivalent reactance} = \frac{6.05}{5.27} = 1.15 \textit{ ohms}$$

Since line *AC* is open at station *C*, station *B* cannot feed in any current to a short-circuit.

The initial symmetrical short-circuit r.m.s. current =

$$\frac{6600}{\frac{2 \times 1.74}{2} + \frac{2.08}{2} + 0.217} = 2200 \textit{ amps.}$$

The maximum unsymmetrical current may be approximately 1.73 × 2200 = 3810 amperes. Equivalent reactance in percent = $\frac{876}{2200}$ × 100 = 40 percent approximately. The current will vary from 3810 amperes at the moment of short-circuit to a lower value, called the sustained value, of approximately 2300 amperes. The curve will be similar to that given in *Trans. A. I. E. E.*, Feb., 1918, Fig. 3, p. 130 for 40 percent reactance, except the sustained value will be about 50 percent higher than shown there, as it has been found that a single-phase short-circuit gives a sustained current approximately 50 percent higher than a three-phase short-circuit. If the generators in station *A* were loaded, the instantaneous short-circuit currents would be approximately the same, but the sustained values would be higher in proportion to the ratio of field currents for the two cases.

(2b) Station A

Initial symmetrical short-circuit currents

$$\frac{6600}{1.74 + 1.04 + (.5 \times 0.217)} = 1710 \textit{ amperes.}$$

Percent equivalent reactance = $\frac{876}{1710}$ × 100 = 51 *percent. Short-circuit current will vary approximately* 3000 *to* 2050 *amperes.*

Station B

Assuming leakage reactance of 10 percent, then the full-load current per phase = $\frac{10\,000 \times 1000}{1.73 \times 2200}$ = 2630 amperes

$$\textit{Generator reactance} = \frac{\frac{10}{100} \times \frac{2200}{1.73}}{2630} = 0.006 \textit{ ohms.}$$

Transformer full-load current

$$\frac{2300 \times 1000}{2200} = 1500 \textit{ amperes.}$$

Transformer reactance

$$\frac{0.065 \times 2200}{1500} = 0.096 \textit{ ohms.}$$

Station C

Transformer full-load current on 33 000 *volt side* = $\frac{1500 \times 1000}{17\,300}$ = 87 *percent*

Transformer reactance referred to 2300 volts $= 12.0 \times \left(\frac{2200}{17\,300}\right)^2 = 0.209$ *ohms.*

Lines BC

4/0 copper, 60 inch vertical spacing. If the line is transposed, equivalent spacing $= \sqrt[3]{60 \times 60 \times 120} = 75.6$ inches. For 75.6 inch spacing, 4/0 copper, the reactance per mile at 50 cycle = 0.605 ohms approximately. 3 000 000 circ. mils aluminum per mile = 0.582 ohms approximately. For 30 miles, the total reactance per line = 30 × 0.605 = 18.5 ohms and 30 × 0.582 = 17.46 ohms respectively. If the two lines are in parallel, the combined reactance = 8.9 ohms.

Initial short circuit current from station B =

$$\frac{2200}{\frac{2 \times 0.048}{2} + \frac{0.096}{2} + \frac{8.9}{7.02} + \frac{0.209}{2} + \frac{10 \times 0.605}{(15.8)^2}}$$

$= 6000$ *amperes*

Percent equivalent reactance

$$= \frac{2630}{6000} \times 2 \times 100 = 88 \textit{ percent.}$$

The short-circuit current will vary from 10 400 amperes approximately to 8700 amperes sustained.

If only one generator in station *B* and one line *BC* are in commission, then

Initial symmetrical short-circuit current =

$$\frac{2200}{0.0.6 + 0.096 + 17.5 + 0.104 + [illegible]}$$

7.02 [illegible]

$= 3670$ *amperes.*

Percent reactance [illegible] 3670 × 100 = 72 *percent.*

The short-circuit current will vary from approximately 6350 amperes maximum unsymmetrical to 5000 amperes sustained. In the above, we have assumed two transformer banks at station *C* both in service. The effect of resistance has been neglected, as this unduly complicates the calculation and is so small compared to the reactance that it can be neglected. Also, capacitance has not been considered. H.W.S

10-3—CHANGING FREQUENCY—Will you kindly advise me in detail how frequency higher than that of the supply line, can be secured by driving a phase wound induction motor at half speed from separate source of power and with the stator connected to its rated source of power?

J.F.S. (IND.)

If voltage is applied to the primary, this higher frequency can be obtained from the secondary by driving the motor in a direction opposite to that which the primary voltage would tend to rotate it as a motor. The frequency obtained will have the following relation to the primary frequency:—

$$\frac{\textit{Freq. Secondary}}{\textit{Freq. Primary}} = \frac{\textit{Syn. r.p.m.} + \textit{r.p.m. of sec.}}{\textit{Syn. r.p.m.}}$$

The voltage obtained from the secondary will have the same relation to the open circuit secondary voltage. T.P.K.

CORRECTION

In the Journal for September, 1920 on page 415, Fig. 8 should have the following sub-title:—

[illegible] both coils. The [illegible] the top coil was 42.7 degrees; in the bottom coil 44.5 degrees. [illegible] degrees [illegible] degrees in the middle packages. The air rise was 2.5 degrees. 25 amperes direct-current in both coils. The rise by resistance in both coils [illegible] degrees in the middle packages. The air rise was 3.5 degrees. 25 amperes direct-current in the top coil and 20 amperes direct-current in the bottom coil. The rise by resistance in the top coil was 66.5 degrees; in the bottom coil 48.7 degrees. The rise of the iron was 17 degrees in the end package and 13.7 degrees in the middle packages. The air rise was 25 degrees.

The 14th & 15th lines, second column, p. 355 should read "current at any power-factor, provided the voltages remain balanced."

THE
ELECTRIC
JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country

The co-operation of all those interested in operating and maintaining railway equipment is invited Address R. O. D. Editor.

OCTOBER
1920

Armature Winding Diagrams for Railway Motors

When armature windings are damaged and require rewinding by the operating company it is very important that the connections are correctly made from the windings to the commutator. If the windings are not too badly damaged, it is the common practice of the winder to note the throw of the leads from coil to commutator bar while stripping the windings, and in this way he gets the desired information. This method cannot be entirely relied upon as there is a possible chance that the winding was connected wrong when it was originally wound, either in the repair shop or the factory. The only safe way is to get this winding information from the manufacturer of the motor. Various methods of showing the necessary information for winding a railway motor armature has been used from time to time and these will be outlined as follows:—

Method 1—Fig. 1 shows six different views arranged for different types of coils, of the commutator end of an armature and commutator with slots and bars lettered, so that this sketch can be used for a large variety of machines. The data for the particular machine in question is tabulated at the side of the sketch, from which the armature can be wound.

Method 2—Fig. 2 shows a development of the armature information given in Fig. 1. By development is meant that we consider the winding placed on a thin cylinder and the cylinder split lengthwise and opened up into a flat sheet. Necessary data is given on this sketch to assist in the correct winding of the armature.

Method 3—Fig. 3 shows a layout of the same armature information as given in Figs. 1 and 2 and is somewhat similar to the one as shown in Fig. 1, but the information only applies to a definite armature. In addition to the armature information, sufficient data is given to make the field winding connections.

Method 4—Fig. 4 shows a layout in which the best points of all previous winding diagrams have been used, with added features which are given to help the winder check his connections. In this sketch the first active coil is called lead *1*, whereas in Figs. 1, 2 and 3 the middle coil in all cases is called lead *1*. This change was made because it seems more logical to call the first coil the *1* lead.

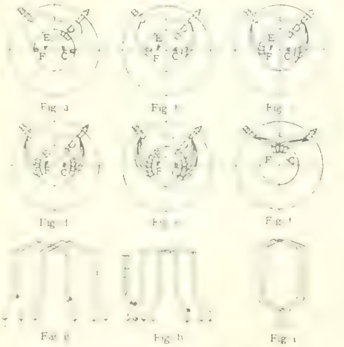


FIG. 1—[illegible] WINDING DIAGRAMS

[illegible] commutator bars, refer to Fig. e. Throw of coils, A-B is 1 to 8: throw of leads; right, C-D, is 1 to 17; left E-F is 1 to 17: and total, C-F, is 1 to 68. The center line of the tooth is on the center line of the mica

Fig. 5 shows a winding layout similar to [illegible] that in this winding, which is for a different [illegible] previously shown, there is an idle coil. The 1 lead of the starting coil only, is always used as the dead coil, and the 2 coil is considered the first active lead.

Any one of the above methods gives the required information to wind an armature and they have been used quite extensively for this purpose, but the layout as shown in method 4, Figs. 4 and 5, has been worked out to show each detailed step and to give all necessary information in such a form as to be readily understood, so that the average winder can intelligently use this diagram in connection with rewinding an armature and feel sure that the work is being done correctly. The final form of this winding diagram as presented herein was the result of a careful study of a number of criticisms on the previous diagrams and was only adopted after being modified and changed in line with numerous suggestions made by practical men familiar with this line of work.

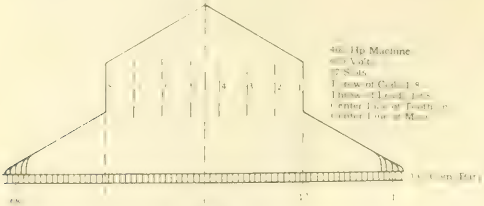


FIG. 2—[illegible]

MOTOR WINDING INFORMATION

A—Railway motors are usually laid out for a wave or two-circuit type of winding.

B—They may be wound with either a right or left hand coil. A right hand coil is one where the leads come out from the right side of the coil when holding the coil with the portion to be placed in the bottom of slot toward you and with the air-gap side of the coil uppermost. A left hand coil is one where the leads come out of the left side of the coil when holding the coil with the portion to be placed in the bottom of the slot toward you and with the air-gap side of the coil uppermost.

C—Armatures of the two-circuit type may be wound either progressive or retrogressive. A progressive wave or two-circuit winding is one when the throw of the coil lead is one-half a commutator bar greater than half way around the commutator. A retrogressive wave or two-circuit winding is one when the throw of the coil lead is one-half a bar less than half way around the commutator. For example with 135 commutator bars, a progressive winding has a coil throw of $(135 + 1) \div 2 = 68$ bars or 1 and 69. A retrogressive winding has a coil throw of $(135 - 1) \div 2 = 67$ bars or 1 and 68.

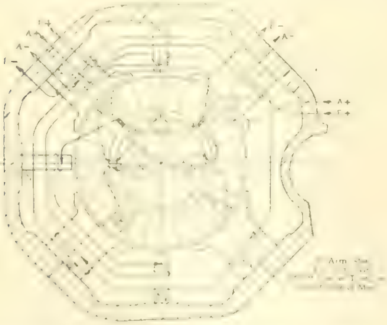


FIG. 3—LAYOUT OF ARMA[illegible] IN FIGS. 1 AND 2

D—The wave or two-circuit windings always require an odd number of commutator bars.

E—When an even number of coils per slot are used there will always be an idle or dead lead.

F—When an odd number of coils per slot are used and there are an even number of slots on the armature there will always be an idle or dead lead.

G—When an odd number of coils per slot are used and there are an odd number of slots on the armature there will never be an idle or dead coil.

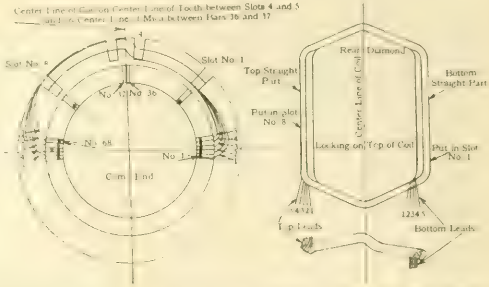


FIG. 4—LAYING OFF AN ARMATURE WINDING WITHOUT DEAD COILS

1.—The center line of the starting coil is on the center line of the armature tooth between the fourth and fifth slots and on the center line of the mica between the 36th and 37th commutator bars.

2.—Starting at bar 36 count back (clockwise) to bar 1 and in this bar place lead 1 from the bottom leads of the starting coil.

3.—Starting at bar 1 count forward (counter clockwise) to bar 68 and in this bar place lead 1 from the top leads of the starting coil.

WINDING DATA

Number of armature slots 27
Number of commutator bars 135
Coils lie in slots 1-18
Leads connect to bars 1-68
Commutator center-punched on end
..:.. Locates the top leads of the starting coil
..... Locates the bottom leads of the starting coil
.. Locates the starting coil in slots 1 and 8

H—The alignment of the armature slots or teeth with respect to the commutator mica or bar is as follows:—

With the coil throw even and the lead throw even, the center line of the tooth will line up with the center line of the mica.

With the coil throw odd and the lead throw odd, the center line of the slot will line up with the center line of the bar.

1.—The center line of the starting coil is on the center line of the armature tooth between the fourth and fifth slots, and on the center line of the mica between the 31st and 32nd commutator bars.

2.—Starting at bar 31 count back (clockwise) to bar 1 and in this bar place lead 2 (the first active coil) from the bottom leads of the starting coil.

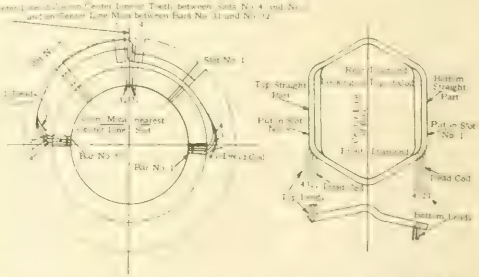


FIG. 5—LAYING OFF AN ARMATURE WINDING WITH ONE DEAD COIL

3.—Starting at bar 1 count forward (counter clockwise) to bar 60 and in this bar place lead 2 (the first active coil) from the top leads of the starting coil.

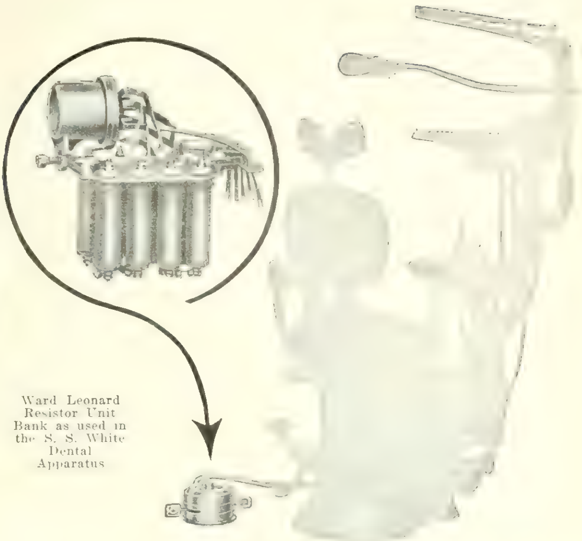
WINDING DATA

Number of armature slots-30
Number of commutator bars-119
Coils lie in slots 1-8
Leads connect to bars 1-60
Commutator center-punched on end
.:. Locates top leads of starting coil.
... Locates bottom leads of starting coil.
.. Locates starting coil in slots 1 to 8.

With the coil throw even and the lead throw odd, the center line of the tooth will line up with the center line of the bar.

With the coil throw odd and the lead throw even, the center line of the slot will line up with the center line of the mica.

JOHN S. DEAN.



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Electrical Specialties Co., Detroit
Lyman C. Reed, New Orleans

NATIONAL SAFETY SECTION

BLAST FURNACES

(Continued)

Cast Houses—Casting holes where ladles are loaded under the floor should preferably be grated. Where gratings are not practicable railings should be provided. Cast house floors should be provided with exits, to prevent men being trapped in event of a breakout. These should be sufficient in width to permit quick escape. A hinged or removable shield, or other efficient means, should be provided, where practical, for all permanent gates in iron and cinder runners so that there will be no danger of the operator being burned.

Substantial removable railings should be provided when the cast house floor is elevated; and where spouts extend considerably outside of the cast house retaining wall, it is suggested that they be provided with a railed platform. Loam boxes should be elevated about thirty inches and provided with covers.

Blowing Engines—It is advisable that the signal whistles in blowing engine rooms be operated by electric power, the switches being located in the cast house. Some companies provide additional switches located at different points in the cast house. It is suggested also that a light be provided at the operating switch to indicate when the circuit is made. Signal lights should be installed in the blowing engine room which will indicate the number of the furnace, so that the engineer will know which furnace is signaling.

OPERATION

Furnace superintendents are not agreed on any one routine of safe operation. They do not follow the same methods, step-by-step, therefore the suggestions here given are not to be considered as the only safe methods to follow. The "blowing out" and "blowing in" of furnaces are operations which, unless properly handled may lead to serious results; there are disputed points, however, and although the practice suggested below is approved by many furnace operators in addition there is included details of a somewhat different pracice followed by one of the blast furnace operating companies in America.

Blowing Out Blast Furnaces—When gas is no longer suitable for use in stoves or boilers, and water seals are to be filled, steam should be immediately turned into dust catchers between water seal and furnaces. All bleeders on dust catchers should be kept closed, thus driving the gas out through the top of the furnace where the bleeders are open. Water sprays should be put in try hole and on big bell. The big bell should be kept partially open, held tight against chains, rods or lugs inserted between bell and hopper.

While blowing out a blast furnace the bell and hopper should never be kept cool by closing the bells tightly and filling the hopper with water. Very disastrous results have occured where this dangerous practice was followed. When, during the blowing-out period, the blast has been taken off at casting time, or otherwise, the water should be shut off on top until blast is again put on. When a furnace is blown out and after the blast is taken off the tuyeres should be plugged with clay and the blow pipes should be taken down one at a time, following in turn around the furnace so that in case any of the scaffolding should fall, the danger to the crew is minimized. The furnace floor should be roped off and no one permitted to go near the furnace except under personal instruction of the foreman. Steam should be kept going into the dust catcher system for at least 24 hours after the blast is taken off the furnace. The blowing engine should not be completely stopped but should be kept slowly running until all blow pipes are down and the tuyeres are plugged with clay. After the tuyeres are plugged, and the blast is completely off, water should be kept going into the top of the furnace until the fire has been drowned out. The wet stock should then be removed from the furnace through the tuyeres and cinder notches.

We give here also the "blowing out" practice followed by a large blast furnace operating company, a member of the National Safety Council.

"(a)—In blowing out a blast furnace it is good practice to follow up the last ore charge witth a blank charge of coke in order to clean off the walls of the furnace and remove scaffolds, etc., which might later break loose and fall while workmen are plugging tuyeres.

"(b)—The blast should be gradually cut to keep pace with the decreased depth of material in the furnace until a safe minimum is reached, sufficient, however, to provide a positive pressure at the water valves under blowing out conditions.

"(c)—The bleeder and water valves are kept open during the blowing out period, and the explosion doors kept closed, but not fastened down. All bleeders and other valves on dust catchers, down comers and gas flues should be kept closed, thus driving out the gas through top of furnace where bleeders are opened.

"(d)—The top of the furnace should be cooled by water sprays preferably keeping the top gas below 700 degrees. The steam generated is also a guarantee against top explosions and the possibility of the gas ignating.

"(e)—The water sprays are best located around the outside of the hopper and around the apex of the large bell. The bell must be kept slightly open (an inch or so) either by blocking the bell beam or by rods or lugs between the bell and its seat. The small bell also must be similarly blocked to prevent any accumulation of water, which, upon opening the bells, would drop into the highly heated furnace interior and produce an explosion from the steam and water gas generated.

"(f)—If, at any time during the blowing out period, the blast is taken from the furnace, the water on top should be stopped simultaneously.

"(g)—At many plants the blast is taken off while the stock is well up on the bosh. It is good practice, however, to continue the blast until the last coke is down to within a few feet of the tuyeres, thus avoiding the labor of raking out a large mass of stock.

"(h)—After the final cast, all men should be ordered from the cast house except those absolutely necessary to the final operations; the mixer valve should be closed, water valves, filled the water shut off on top, both bells opened, snorter valve opened and cold blast valve at stoves closed. It is also good practice to admit steam into the dust catcher just before opening the bells. Steam is left on furnace several hours after furnace is off.

"(i)—The furnace is cast as dry as possible on the last cast. Any iron and cinder remaining is allowed to solidify, this being later removed in form of a salamander. It is advisable to keep tapping hole open after blast is off, to permit any slag to run out.

"(j)—Considerable success has been had recently by making a second cast of the last iron and cinder after the blast has been taken off through a hole drilled into the bottom of the hearth below the jacket. The metal is run into sand beds. In this case if the cast is to be made after the furnace is off, stock in furnace is kept just below the mantle.

"(k)—Sufficient time having elapsed after the first cast, the tuyeres are plugged with the blow pipes in place, and the water gradually turned on again on the furnace top. The tuyeres should be plugged one at a time, following in turn around the furnace, so that in case any scaffolding should fall the danger to the crew is minimized. After tuyeres are plugged, the furnace is thoroughly drowned out, then blow pipes can be removed and engines stopped, and the stock can be raked out from tuyeres and cinder notch.

"(l) The downcomers, dustcatchers, gas line doors and bells should be kept closed for 24 hours after the furnace is out, steam being admitted through the dustchatcher during this time and allowed to go through the furnace top, where the bells and bleeders are kept wide open. After this, the goggle valves or main water valves leading from dustchatcher should be closed; work can then be started on the furnace."

BLOWING IN BLAST FURNACES

After the furnace is lighted, it should be allowed to stand under natural draft, and no charging should be done until the blow pipes are up and blast is on the furnace. Blow pipes should never be put up until after the blowing engines are turning over. All fire should be kept away from the gas burners at the stoves and boilers until the gas pressure forces the air out of all gas mains, and forces gas through every crack and crevice in the whole gas main system. Then the burner farthest from the furnace should be lighted and as the flow of gas increases, more burners under the boilers and stoves can be lighted.

(To be continued)

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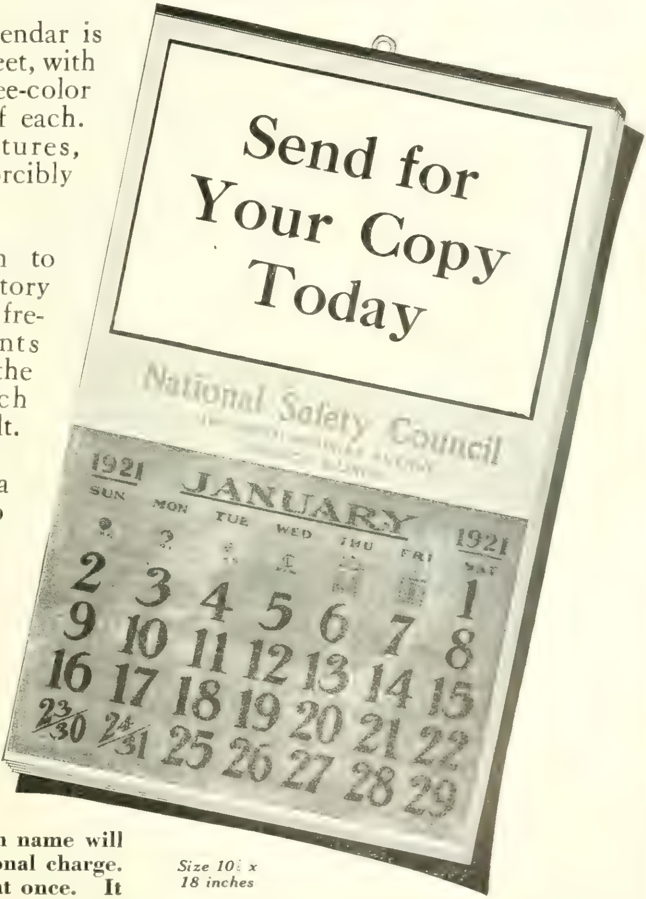

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A. E. R. A. CONVENTION

The Thirty-ninth Annual Convention of the American Electric Railway Association, scheduled for the week October 11-15, promises to be one of the most important in the history of the Association. A glance at the program given below reveals the importance of the subjects to be discussed, such as problems of fuel supply, valuation, fare systems, public and national relations. Reservations for exhibit space this year indicate the largest and most interesting display of railway apparatus ever held during a convention. The programs of the American Association, Engineering Association, and Transportation and Traffic Association are as follows:—

MONDAY, OCTOBER 11

9:30 A. M. to 12:30 P. M.

Registration and distribution of badges, Young's Million Dollar Pier.

2:30 P. M. to 5:00 P. M.

ENGINEERING ASSOCIATION

Annual address of President.

Reports of Executive Committee, Secretary-Treasurer, appointment of Committee on Resolutions.

Reports of Committees:—

Way Matters—R. C. Cram, Engineer of Surface Roadway, Brooklyn Rapid Transit, Brooklyn, N. Y. Chairman.

Buildings and Structures—D. E. Crouse, Chief Engineer, Rochester & Syracuse Railroad Co., Inc., Syracuse, New York. Chairman

T. & T. ASSOC.

Annual Address of the President.

Annual Reports of Executive Committee, Secretary-Treasurer, appointment of Convention Committees on:—

(a) Resolutions.
(b) Nominations.

Joint meeting with the Accountants' Association.

Report of Committee on Collection and Registration of Fares.

Joint meeting with Claims' Association.

Report of Committee on Code of Traffic Principles. Paper—"Automobile Hazards," C. M. Talbert, Commissioner of Streets and Sewers of St. Louis and Chairman of Public Safety Section, National Safety Council.

TUESDAY, OCTOBER 12

9:30 A. M. to 12:30 P. M.

AMERICAN ASSOCIATION

Annual Address of the President.

Annual Reports of Executive Committee, Secretary-Treasurer, appointment of Convention Committees on:—

(a) Resolutions.
(b) Nominations.
(c) Recommendations in President's Address.

Reports of Committees on:—

(a) Compensation for Carrying U. S. Mail—V. C. Curtis, Chairman, Secretary, The Connecticut Company, New Haven, Conn.

(b) Electrolysis — Calvert Townley, Chairman, Asst. to President, Westinghouse Electric & Mfg. Co.

(c) National Relations—Charles L. Henry, Chairman, President, Indianapolis and Cincinnati Traction Company, Indianapolis.

Address:—"Problems of Fuel Supply" —Eugene McAuliffe.

Reports of Committees:—

(d) Publicity—Barron Collier, Chairman, President, Barron G. Collier, Inc., New York, New York.

(e) Committee of One Hundred—Guy E. Tripp, Chairman, Westinghouse Electric & Mfg. Company, New York, N. Y.

Discussion of Report of the Federal Electric Railways Commission.

2:30 P. M. to 4:30 P. M.

JOINT MEETING OF ENGINEERING ASSOC. WITH T. & T. ASSOC.

Report of the Committee on Safety Car Operation—C. W. Kellogg, Stone & Webster, Chairman.

4:30 P. M. to 5:30 P. M.

Paper:—"Standardization and its Effect on Stores."

(a) "From a Store Keeper's Standpoint," P. F. McCall, Storekeeper, South Side Elevated Railroad Company, Chicago, Ill.

(b) "From the Purchasing Agent's Standpoint," By a Purchasing Agent.

WEDNESDAY, OCTOBER 13

9:30 A. M. to 12:30 P. M.

AMERICAN ASSOCIATION

Reports of Committees:—

(a) Fare Systems—W. H. Sawyer, Chairman, Vice-President E. W. Clark Management Corp., Columbus, Ohio.

(b) Aera Advisory—R. B. Stearns, Chairman, Vice-President Eastern Mass. Street Railway Co., Boston, Mass.

(c) Company Membership—F. R. Coates, Chairman, President Toledo Railways and Light Company, Toledo, Ohio.

Paper:—"Possibilities of Transporting Other Than Passengers."

(a) Urban Lines—Col. A. R. Piper.

(b) Interurban Lines—Britton I. Budd.

Address:—"Training of Electric Railway Personnel"—Martin Schreiber.

Address:—"Settlement of Labor Disputes in the Interest of the Public and its Influence on Fares"—Governor Allen.

2:30 P. M. to 5:00 P. M.

ENGINEERING ASSOC.

Reports of Committees:—

Power Distribution—Chas. R. Harte, Construction Engineer, Connecticut Co,, New Haven, Conn. Chairman.

Power Generation—A. B. Stitzer, Chief Engineer, Republic Engineers, Inc., New York. Chairman.

National Electrical Safety Code—J. H. Libbey, Electrical Engineer, Eastern Mass. St. Ry. Co., Boston, Mass. Chairman.

Address—"The Superpower Line"—W. S. Murray, Superpower Survey, United States Geological Survey. Chairman.

THURSDAY, OCTOBER 14

2:30 P. M. to 5:00 P. M.

ENGINEERING ASSOC.

Reports of Committees:—

Equipment—Daniel Durie, General Superintendent, West Penn Railways Co., Connellsville, Pa. Chairman.

Heavy Electric Traction—Sidney Withington, New York, New Haven & Hartford Railroad Co., New Haven, Conn. Chairman.

Standards—H. H. Adams, Superintendent of Shops and Equipment, Chicago Surface Lines, Chicago, Ill. Chairman.

Address—"Electrification of Railroads"—A. H. Armstrong, Electrification Committee, General Electric Co., Schenectady, N. Y. Chairman.

Election of Officers.

Installation of Officers.

T. & T. ASSOC.

Report of Committee on Economics of Schedules—Edward Dana, General Manager, Boston Elevated Railway Co. Chairman.

THURSDAY, OCTOBER 14

9:30 A. M. to 12:30 P. M.

AMERICAN ASSOC.

Reports of Committees:—

(a) Valuation—Col. P. J. Kealy, Chairman, President Kansas City Railways Co., Kansas City.

Paper:—"Rate of Return"—Cecil F. Elmes.

Paper:—"Place of the Botor Bus"—F. C. Pick; "Place of the Motor Bus as a Supplement to Electric Railways"—R. G. Smith.

Address:—"The Motor Vehicle—Competitor or Ally?"—Geo. M. Graham.

Address:—"An Outside View of the Electric Railway Industry"—Melville E. Stone.

Reports of Convention Committees:—

(a) Recommendations in President's Address.
(b) Resolutions.
(c) Nominations.

Election of Officers.

Installation of Officers.

2:30 P. M. to 5:00 P. M.

ENGINEERING ASSOC.

Reports of Committees:—

Way Matters—R. C. Cram, Chairman, Engineer of Surface Roadway, Brooklyn Rapid Transit Co.

Buildings and Structures—D. E. Crouse, Chairman, Chief Engineer Rochester & Syracuse Railroad Company, Syracuse.

Election of Officers.

Installation of Officers.

T. & T. ASSOC.

Reports of Committees:—

Express and Freight Traffic Facilities and Costs—P. P. Crafts, Manager Freight Department, Eastern Massachusetts Street Railway Company, Boston. Chairman.

Merchandising Transportation—F. G. Buffe, General Manager, Kansas City Railway Co. Chairman.

PERSONALS

Mr. G. S. Sawin, formerly of the Public Service Electric Co., has become connected with the Westinghouse Electric & Mfg. Co. as assistant to manager of the supply department at East Pittsburgh.

Mr. L. C. Richards, district service manager at New York, has been placed in charge of the electrical service department of the Westinghouse Electric & Mfg. Co. with offices at East Pittsburgh.

Prof. E. A. Hitchcock, vice-president of the Bailey Meter Co. of Cleveland, has been appointed dean of the college of engineering of Ohio State University, Columbus.

Mr. Edward W. Harry, electrical engineer of the National Tube Company, McKeesport, Pa., has resigned to become chief electrical engineer of the Pittsburgh Steel Co., Monessen, Pa.

Mr. Alfred M. Staehle has resigned the editorship of Blast Furnace and Steel Plant of Pittsburgh to accept a position with the publicity department of the Westinghouse Electric & Mfg. Co. at East Pittsburgh, where he will be in charge of publicity work for the industrial department.

Mr. Martin Schreiber, chief engineer of the Public Service Railway of New Jersey, has been appointed manager of the southern division of the Company with headquarters at Camden.

Mr. W. J. Kaup, formerly general supervisor of tools, Westinghouse Electric & Mfg. Co., has resigned from his position of chief engineer of the Crucible Steel Co. of America to devote his entire time to his consulting engineering work.

Mr. Lesley C. Paul, formerly of the editorial department of the *Electric Railway Journal,* is now connected with the publicity department of the Westinghouse Electric & Mfg. Co. in charge of railway publicity.

Mr. S. H. Abbott who was with the Westinghouse Electric & Mfg. Company in the Baltimore Service Department from 1909 to 1917 and was in France as an officer in the engineering corp during 1917 to 1919, has recently returned from an installation trip to Luchon, France, where he went to install two 122 000 volt outdoor substations and has taken up work with the Westinghouse Electric International Company at East Pittsburgh.

NEW BOOKS

"Wiring for Light and Power"—Terrell Croft, 455 pages—426 Illustrations. Pocket size. flexible—Published by McGraw-Hill Book Company. For Sale by The Electric Journal, Price $3.00.

This is the second edition of this work originally published in 1917 and contains modifications corresponding to changes in national electrical code on which the entire book is based. Sections of the code are given in small type and explanations in detail in larger type. To those who wish to become acquainted with the approved methods of installing electric apparatus a review of this book certainly should be decidedly helpful, as it is much more easier to understand than the code text itself. Various wiring schemes are illustrated showing methods which have been found most suitable for various arrangements of circulation.

"Electrician's Handy Book"—T. O'Connor Sloane. 825 pages, 600 illustrations. Published by The Norman W. Henley Publishing Company. For sale by The Electric Journal. Price $4.00.

This is the fifth edition of this handbook originally brought out in 1905. It contains 46 chapters and is written in elementary form. Some elementary mathematics is given in the first chapter and some fundamental electrical information in the second, third and fourth chapters with reference to electrical units. Three chapters are devoted to electrical chemistry and batteries, followed by chapters on magnets and induction. Several chapters are devoted to direct-current machines and the same applies to alternating-current machines. This book attempts to cover the entire field, hence includes sections on arc and incandescent lamps, telephony, wireless telegraphy, electric furnaces, lifting magnets, various types of meters, lightning arresters, etc.

"Office Administration"—J. William Schulze. 295 pages, 30 illustrations. Published by McGraw-Hill Book Co. Price, $4.00.

This book aims to present a thorough discussion of the principles and methods which underly efficient and economical office management for the use both of the potential executive and those who have already arrived. The author is also the author of "The American Office" published several years ago and the present book is somewhat along the same lines. Considerable space is devoted to the selection and training of office employees, using modern methods. Office layouts are given detailed attention, showing those arrangements which have been found most satisfactory in use. Examples are given of office layouts used by various prominent concerns. Only a small number of forms is used as these must ordinarily be designed particularly for each application. This book should be of considerable interest to any one having to do with general office administration.

NEW CARBON BRUSH CATALOGUE ISSUED

The National Carbon Company of Cleveland, Ohio, has released to the trade their new motor and generator brush catalogue No. 35, in which the well known line of Columbia Pyramid Carbon Brushes is described and illustrated. The catalogue is designed to assist the operator as well as the engineer toward a better understanding of brushes, and in preparing it the problems of manufacturers, designers and operators have been borne in mind. If, however, further information on any particular grade is desired, the engineering department of the National Carbon Company will be glad to supply it.

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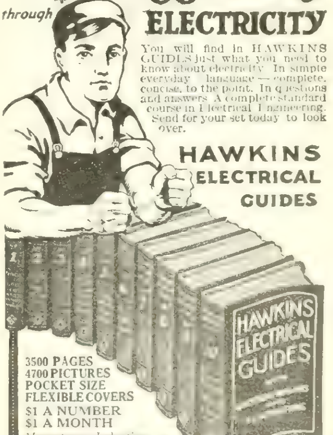

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THE ELECTRIC JOURNAL

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NOVEMBER, 1920

NO. 11

Ventilated Motors for Hoist Work

It has been generally recognized that crane and hoist motors should be protected against dirt, dust and falling particles. The new design, described by Mr. F. L. Moon in the article on "Direct-Current Motors for Crane and Hoist Work", is enclosed to give this protection, but has small openings in the front and rear brackets to allow free passage of air without unnecessarily exposing the winding and commutator of the motor.

The increased ventilation thus obtained materially reduces the temperature rises in the motor; or, to state it another way, increases the rating. This increase is much greater on the continuous rating than on the short-time rating. That is, of two motors which have the same short time rating, the ventilated motor will have a much higher continuous rating than the non-ventilated motor. This continuous rating, from the standpoint of temperature rise, is the true measure of the work the motor will do.

A crane motor of ventilated, enclosed design can be built with less total height than a non-ventilated motor. This is frequently a matter of importance in crane designs, where only small overhead room is available.

A small diameter armature is used, resulting in a very low armature inertia. In ventilated designs the inertia effect of the armature is only one-third to one-fourth of that found in similar non-ventilated designs. A material saving of power results from this lower armature inertia, in applications where frequent reversing is encountered; also there is less wear and tear on the brakes and mechanical parts of the motor.

To summarize, the ventilated design has the advantages of higher continuous rating, smaller over-all dimensions and less power consumed in starting and stopping, than in similar designs which are not ventilated.

L. C. McClure

Electric Power for Refrigeration

The manufacture of artificial ice has, from its inception, been associated in the popular mind with a boiler plant and one or more stacks producing large quantities of black smoke down by the railroad. It was generally assumed that the ice must be manufactured from distilled water, which required an extensive boiler plant; and that, with the boiler plant already at hand, the power required for the refrigeration process could be obtained almost for nothing by running the steam first through the engine which drove the ammonia compressors. The idea of locating such a dirty and noisy establishment in the heart of a residence district was unthinkable, even where it was recognized that the ice would cost less if it did not have to be hauled so far, an idea which was usually given but scant consideration.

In recent years, however, the rising cost of labor and local transportation have caused them to become a disproportionate factor in the total cost of the delivered product. It began to be seen, especially in the larger cities, that some means of manufacturing the ice close to the center of distribution was highly desirable. This idea was emphasized in the case of large hotels, storage warehouses, etc., where the manufacture of ice was largely eliminated by the use of direct refrigeration with cold brine. The electric motor solved the problem of noise and dirt for such installations. Distilled water for the small quantity of ice needed for drinking water, etc., was obtained as a byproduct of the heating system, or this ice was purchased outside.

Distilled water was necessary for two reasons. The water supply was frequently muddy and, even where the water was sufficiently pure, small particles of air freezing in the ice produced a cloudy appearance.

In recent years both these objections to "raw water" ice have disappeared. In practically all of our cities, the water supply is clean, due either to extensive filtration plants or to an aqueduct bringing water from a clean source. As described by Mr. Carlsen in this issue, the cloudy effect has been completely eliminated by various processes of agitating the water during freezing, which produce ice as clear as any manufactured from distilled water.

Raw water ice has practically revolutionized the ice making business. The modern electric motor-driven ice plant is clean and noiseless, and when housed in a suitable building is not detrimental to the finest residence district. In fact, as shown by the map in Mr. Carlsen's article, such plants are scattered throughout the best residence districts of Chicago, and the same condition is rapidly being reached in other cities. Since the small motor-driven iceplant is, within limits, almost as efficient as a much larger plant, such locations mean much in reducing the ultimate cost of the ice.

The small motor-driven ice plant, located close to the center of distribution represents, therefore, the ultimate idea in the present system of preserving food stuffs by the use of ice. It can only be replaced by the still greater improvement, which is sure to come in the future, of having a miniature motor-driven refrigerating plant in each home, so that the wholesale manufacture and distribution of ice will be entirely unnecessary.

Chas. R. Riker

Electrical Refrigeration

C. J. CARLSEN
Commonwealth Edison Company

SOME YEARS ago no difficulty would have been experienced by central station interests in giving the number, size, capacity and even performance of the electrically-operated refrigerating machines or plants in any part of the country. Today such general information would be impossible, for the number of electrically-operated installations has increased so enormously during the past three years as to have made it impossible for anyone interested to keep in close touch with such developments. Nor have war conditions been responsible for such rapid growth excepting in an indirect manner. True, the urgent need for greater economy was a vital factor and so far as central station service was concerned a great help, yet the economic possibilities of the electrically-operated plant using central station service existed before just as well as after the war.

Prior to the war the central stations had confined their energies mostly to securing the electrification of new plants, that being the path of least resistance, and for such cases there are indisputable arguments made possible through the success of manufacturing ice from raw or practically untreated water. Existing plants, however, were an entirely different problem. They were already complete units and, with the exception of a few plate ice plants, all were manufacturers of distilled water ice and used steam, gas, oil or producer gas engines as prime movers.

To those of the central station industry who have attempted to prove to the distilled water ice manufacturer the equality of raw water ice as compared with his distilled water product no more need be said. Those who have not had that privilege have missed a splendid opportunity of using their fighting ability to its utmost.

Then came the world war and the distilled water ice manufacturer was confronted with these serious problems:—the shortage of labor, shortage of fuel and the fact that his product—presumably far superior in his judgment to raw water ice and costing considerable more to manufacture—received no more consideration at the hands of the public than the ordinary raw water ice. And we had been telling him this for years but he would not listen. Now with production costs mounting and plant troubles increasing, he was compelled, from the viewpoint of self-preservation, to do what he had consistently refused to do, make a thorough and comprehensive study and comparison between his present plant and its operation as against electrification and central station service. We are all aware as to what the result has been, for almost daily we hear of plants being changed to electric drive in all parts of the country from the Atlantic to the Pacific and from Canada to Mexico.

As previously stated, this electrification of ice and refrigeration plants has been so general throughout the country and so stupendous that no attempt has been made to keep in touch with its growth except in a general way. For that reason the following will be confined almost entirely to the Chicago territory.

Some general idea of the business of ice manufacture and refrigeration in this territory can be had from Fig. 1. The total load indicated is approximately 33 638 horse-power and represents large ice and refrigeration loads only. It does not include a 3000 horsepower load with service purchased indirectly from the central station on a resale basis nor a 2600 horse-power load just across the line outside the Chicago territory. Neither does it include refrigeration loads of relatively large size in markets, hotels, restaurants, theaters and packing houses.

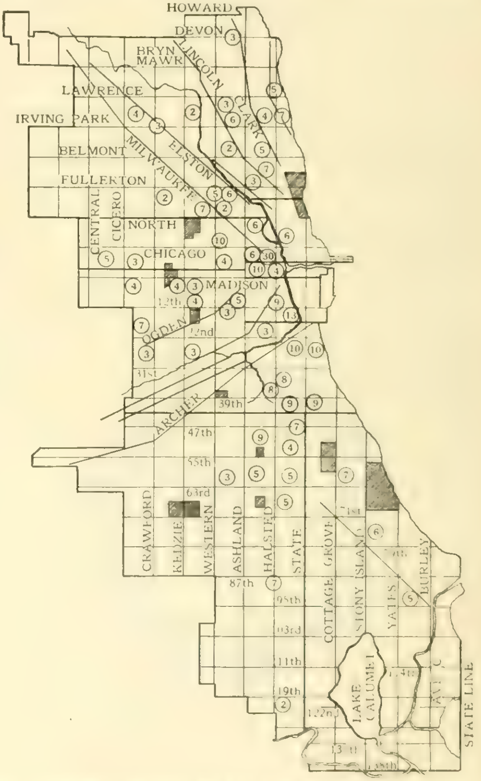


FIG. 1 LOCATION OF LARGE ICE AND REFRIGERATION PLANTS USING CENTRAL STATION SERVICE IN CHICAGO
The numbers in the circles indicate hundreds of horse-power.

At the close of 1918, there were 32 large refrigeration plants on central station service. Twenty-three of these plants were exclusively ice making, one ice making and cold storage and eight combination ice and ice cream. They produced 643 113 tons of ice, 1 543 344 gallons of ice cream and consumed 32 610 868 kw-hr. The total connected load was 13 431 hp. with a combined maximum summer load of 9589 kw. The kw-hr. consumption also included the charging of about 60 electric delivery trucks of from three to six tons capacity and necessary lighting service for the various plants. In addition there were two large cold storage plants having a connected load of approximately 2400 hp. with a combined maximum of 1079 kw for the year and a consumption of 3 935 640 kw-hr. The average kw-hr. per ton of ice—yearly record combined—for the twelve best plants was 43.2 the lowest being 38.5 kw-hr. The yearly load factor of the entire refrigeration and ice manufacturing load was 37.8 percent.

For this year six steam-driven distilled-water ice plants were changed to raw water plants and electrically-operated from central station service and one electrically-operated distilled-water plant was changed to a raw-water plant. At the close of the year 1919 there were 41 large ice and refrigeration plants on central station service with a total connected load of 18 215 hp., a combined service maximum of 12 907 kw and a consumption of 55 713 226 kw-hr. Of this latter amount 49 754 000 kw-hr. were used in the production of 1 056 093 tons of ice or an average of all plants of 48 kw-hr. per ton, although the best plant produced at the yearly rate of 37 kw-hr. per ton. The annual load factor of all plants was 45 percent.

So far, for 1920, 17 new plants have been added, making a total of 58 plants and a connected load as previously stated of 33 638 hp. Of the 17 additional plants, five are new ice making plants exclusively, four are ice and refrigeration, four are combination ice and ice cream, one is a large cold storage plant, one is a raw-water steam-driven plant changed to raw-water electric and two are packing house ice and refrigeration plants. In addition to the above, four of the old plants are practically doubling their equipment and service capacity output. A unique feature of these new plants is that of the 17 all but three will have synchronous motors, direct connected to compressors, with speeds ranging from 72 to 150 r.p.m. and in sizes from 150 to 650 horse-power.

One of the greatest difficulties attending a plant change from any type of prime mover other than electric to electric drive has been the lack of space for installing the motor and belt drive. The advent of direct connection, combined with a slow motor speed, makes it possible to cope with any existing situation, for with direct connection there is not only an actual saving in space, but in cost of installation as well.

Another new development is a synchronous motor designed for direct drive in which the flywheel effect is absorbed by the motor, no fly wheel being used on the compressor. Already reports have come from the West of the successful test and operation of such a unit and its confirmation will be awaited with a great deal of interest, for such a unit offers still greater possibilities for the central station.

Many industries have refrigeration units, steam driven, in too good a condition physically to scrap and yet, because of limitation of housing and flywheel space, electrification in the ordinary sense is impossible. A motor that will fit into such a space and carry with it the possibility of flywheel effect will meet with a most hearty welcome.

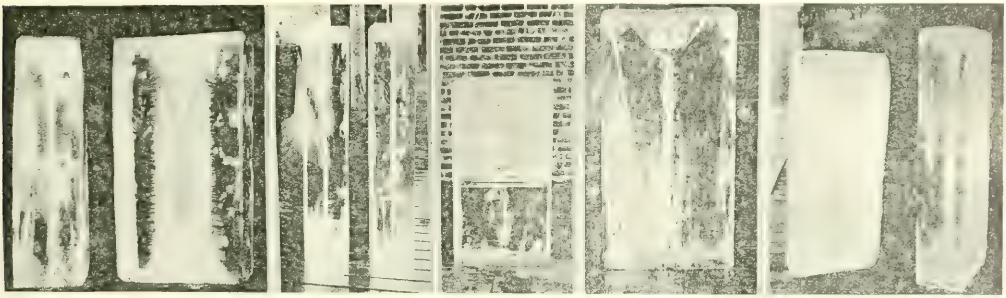

(a) (b) (c) (d) (e)

FIG. 2—DISTILLED AND RAW WATER ICE MANUFACTURED BY DIFFERENT PROCESSES

Another matter of interest is the present method of serving these customers from central stations. The customer supplies a room approximately 17 by 40 by 12 ft. high; 10 by 17 ft. being for line room and approximately 17 by 30 ft. for transformer room. Service is from the 12 000 volt underground system and is fed directly from the generating station through the customer's line room equipped with automatic relays and back to the generation station as a loop connection, thus supplying the customer with the greatest possible assurance of continuity of service. Usually from eight to ten customers are supplied from one such loop service.

In the data on kw-hr. per ton of ice produced it must be borne in mind that these are the average conditions of a large number of plants. Chicago has every conceivable type of raw water ice plant with but one exception—the plate ice plant. True, many of these plants are not as modern as new plants of the same general type would be, yet operating results would not be far different between the two as a relatively small number of improvements have been brought out in the past five years or so in the matter of raw water ice manufacture.

[illegible]

[illegible]

In general there are but two methods in use in the manufacture of raw water ice, the simple drop-pipe low-pressure system wherein air for agitation of fresh water in freezing is carried at a pressure sufficient to overcome the static head of water in cans, and the so-called high-pressure system, where the air is carried at a high pressure in order to dehydrate before being released in the cans. The term high-pressure, however, is a misnomer so far as air pressure used for agitation of freezing water is concerned, as they are both practically at the same pressure when released to the cans. The reason why one system can use ordinary air at pressures slightly above the static water head of the water in the cans whereas the other system requires much higher pressure, is obvious. With the low-pressure drop-pipe system, the air tube is located in that part of the ice cake last to freeze or close; it can therefore be withdrawn just previous to the closing period, the remaining liquid removed and replaced with fresh water and then left to close. Any interruption to the air circuit would only temporarily stop agitation but the air tube would not freeze up. When air pressure is again restored agitation is immediately renewed. With the high-pressure system, the air tube may or may not be rigidly fastened to the can, but the tube during at least the greater part of the freezing period, will be within the freezing zone where the temperature may be 15 to 20 degrees F below freezing. For that reason it will at once be apparent that dry air or air free from moisture must be supplied, else moisture will collect and freeze within the air tube, shutting off the air supply so necessary to the manufacture of clear raw water ice. Again it will be clear that the high-pressure system will require slightly more power in producing a ton of ice, all other factors being equal, than the single-drop pipe system, but there are strong advocates for the system, who claim a better and clearer product can be produced and a saving in labor effected that will more than make up for the difference in power.

FIG. [illegible] CONNECTED TO A HORIZONTAL DUPLEX COMPRESSOR

Fig. 2 is a composite picture showing the quality of ice as manufactured by the different processes. (a) shows distilled water ice. (b) shows ice manufactured by the ordinary drop pipe system, producing a core section in the middle of the cake. (c) shows ice made by the high-pressure system with air released at the bottom of the can. The sample shown in (d) was also made by the high-pressure system, the air tube being supported on the top edge of the can and the tube frozen in, during the process of manufacture. The tube is released by applying a steam or warm water needle; the hole left in the ice cake upon removal of the air tube can be seen in this illustration. (e) shows samples of opaque and clear raw-water ice side by side, the cake to the left showing air failure, with no water agitation during freezing, and that to the right being made by the ordinary drop pipe system; upon close inspection the core of this cake is found to be very thin and feathery. Sample (a) and the ice cake on the left of (e) are similar in one respect in that neither were supplied with air during the process of freezing. They differ however in that (a) was made of distilled water, with the air and impurities, both soluble and insoluble, removed through the process of boiling, reboiling and filtering, so that no agitation is required during freezing to produce clear ice. (e) however, had only a portion of its impurities removed through chemical or

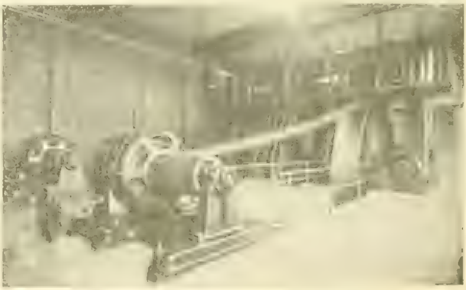


FIG. 5—BELT DRIVEN COMPRESSORS

Compare the amount of space required for this installation with those shown in Figs. 3 and 4.

filtering process or both, and required continual agitation of the water in freezing in order to produce clear ice through continual movement of the water during freezing.

In analyzing various plants in regard to the kw-hr. per ton of ice produced, differences are found in manv instances, due to local conditions either as to system or operation and in a few cases the lack of a true heat balance in the plant. This latter is a feature now being taken up in many of the plants and we may expect more uniform results in plants having similar systems and installations. In this respect there is one thing worthy of note and that is, one of our oldest plants having the simple drop-pipe system is performing as well today as it did when first started ten years ago, and the yearly average remains very constant, averaging from 41 to 43 kw-hr. per ton of ice produced on a yearly basis. In connection with the above statements as to differences in kw-hr. per tons of ice produced in various plants, comparison between two plants of about the same capacity given in Table I will undoubtedly be interesting. Both of these plants use the simple drop-pipe system and near enough in size and output to present a good comparison. It is not the intent here to go into the causes responsible for the differences in plant production as indicated above, but merely to take two plants as nearly identical as possible and show that such differences do occur and how easy of detection these inequality are due to the electrical operation of the plants.

[illegible]

CAN HOIST

The usual installation has been [illegible] can hoist, with the exception of a very few cases where multiple can hoist has [illegible] twelve 400 pound hoist.

TABLE I—COMPARISON OF OPERATING RESULTS FOR THE YEAR 1919

	Plant No. 1				Plant No. 2			
Month	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Jan.	840				53			
Feb.	[illegible]	[illegible]	70		[illegible]	[illegible]	[illegible]	[illegible]
Mar.	[illegible]	218	[illegible]	47	[illegible]	188	[illegible]	27
Apr.	137 760	218	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
May	[illegible]	221	[illegible]	[illegible]	[illegible]	248	3400	33
June	113 600	250	2690	42	157 443	255	3744	42
July	[illegible]	272	3029	60	169 597	258	[illegible]	43
Aug.	187 360	275	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Sept.	[illegible]	282	[illegible]	[illegible]	168 528	257	[illegible]	43
Oct.	[illegible]	281	[illegible]	57	110 453	255	3028	[illegible]
Nov.	[illegible]	218	1350	[illegible]	23 014	75	988	24
Dec.	[illegible]	38	108		108			
Total	1 327 040	[illegible]	[illegible]	[illegible]	[illegible]	258	29 [illegible]	[illegible]

In such plants it is not necessary to take monthly checks; it can be done every day and is done in the best regulated plants and, whenever plant irregularities occur, they are investigated immediately and eliminated.

The following information for central station men has just been received from Mr. Furness—erecting engineer for the John Morrell Packing Company of Sioux Falls, South Dakota.

[illegible]

Installed in the Greenview plant of the Lincoln Ice Co., Chicago. These cranes each have a three motor equipment for the rack, travel and hoist, and will pay for themselves in labor saved in less than three years.

This installation consists of a 375-400 hp, three-phase, 60 cycle, 2300 volt, synchronous motor, direct connected to the crank shaft of a 15 by 36 inch horizontal compressor of 250 tons capacity at 72 r.p.m. No flywheel is used on this compressor, the flywheel effect being supplied by the motor rotor which weighs 187 000 pounds. To start from dead stop to full running speed 15 seconds are required with 130 amperes at pull-in. This is the first installation of its kind where the motor rotor has taken the place of the flywheel for compressor work. The data shown in Table II were obtained during a test made by Mr. Furness when the machine was first started up.

TABLE II—TEST ON SYNCHRONOUS MOTOR DIRECT-CONNECTED TO A 250 TON COMPRESSOR

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10 A.M.	00000	–	2270	1.00	[illegible]	16	[illegible]	[illegible]
11 A.M.	00230	55	2280	1.00	100	[illegible]	[illegible]	[illegible]
12 N.	00390	60	2300	1.00	104	[illegible]	[illegible]	[illegible]
1 P.M.	00550	55	2280	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2 P.M.	00700	55	2300	1.00	104	[illegible]	[illegible]	[illegible]
3 P.M.	00860	55	2280	1.00	102	[illegible]	[illegible]	[illegible]
4 P.M.	01035	–	2300	1.00	104	[illegible]	0	[illegible]
5 P.M.	[illegible]	[illegible]	2200	1.00	[illegible]	[illegible]	[illegible]	[illegible]
8 P.M.	01700	[illegible]	2300	1.00	100	2	[illegible]	[illegible]
9 P.M.	01850	45	2300	1.00	[illegible]	3	2	115
10 P.M.	02000	45	[illegible]	1.00	101	4	5	[illegible]
11 P.M.	[illegible]	60	2300	1.00	[illegible]	[illegible]	3	170

By far the greater part of central station efforts up to date have been directed toward obtaining the ice manufacturing business. But there still remains a very considerable load in steam-driven equipment in cold storage plants.

There is absolutely no reason why electrically-operated plants should not be as desirable and efficient for cold storage plants as for ice manufacturing, as they are both refrigeration problems, but for various reasons cold storage interests having old plants have not been very receptive until recently. We are now getting inquiries from these concerns and this condition, with the fact that slow-speed synchronous motors possible of direct connection to their present compressor units are obtainable, will be a large factor in procuring this business.

There is another type of refrigeration load destined —unless all signs fail—to play a very important part in the future—theater refrigeration. We all know how rapidly restaurant refrigeration has spread in first class dining resorts—why should not the same thing occur with high grade theaters. Two Chicago theaters installed such systems last season with most gratifying results, and two new theaters now under construction are being equipped with elaborate air-washing and cooling systems, the owners taking the stand that the best is none too good for their patrons. The refrigeration load in the two theaters equipped last year was 107 hp in one and 110 hp in the other. One of the new buildings under construction will have a 250 hp refrigeration load and the other 350 hp.

Testing Insulators in Factory and Field

LESLIE N. CRICHTON
Research Engineering Dept.
Westinghouse Electric & Mfg. Company

THE TESTING of line insulators can naturally be divided into three different groups:—*1*—Routine tests in the factory; *2*—Rating tests in the laboratory; and *3*—Field tests for the purpose of eliminating insulators which have become defective in service.

FACTORY TESTS

After the insulator parts have been taken from the kilns and have passed the porosity tests and several inspections for obvious defects, they are placed in an inverted position on a testing table and subjected to a continuous flashover potential for a definite period of time, usually five minutes. It is frequently specified that no insulators shall fail during the last three minutes of the test and, if an insulator should fail during that period, the test is continued until three minutes elapse after the last failure. The top of the testing table is a shallow pan containing a small amount of water, and water is usually poured into the pin-holes of the insulators.

The connections are made as in Fig. 1. The voltage is regulated by means of a regulator and a series resistance is placed in the circuit for the purpose of limiting the power current when the insulators flash over.

The method of applying the test is to raise the voltage to a value somewhat above that which is necessary to flash over the insulator. As a result one of the pieces will flash over before the voltage wave has reached its maximum and the energy which has been stored in all the pieces, acting as electrical condensers, will be discharged through the arc. This causes an oscillating discharge of high frequency and voltage which is superimposed on the 60 cycle wave. The test voltage is so adjusted and the number of pieces on the table so fixed that practically every insulator is subject to the flashover, as is evident from Fig. 2. Considerable noise accompanies this method of testing and a considerable amount of ozone and nitric acid are generated which cause some discomfort to the operators.

The high frequency oscillations which are set up in this circuit detect the minutest defect in an insulator and frequently find flaws which do not interfere in any way with its serviceability. Fig. 3 shows an insulator which had a small crack in one of the ribs before the glaze was applied. This crack was entirely sealed during the firing of the piece; nevertheless the continuous flashover caused the flaw to heat enough that the rib was broken off during the test.

After the porcelain parts are tested, they are cemented together and allowed to stand for several days. Cemented cap and pin type suspension insulators are then tested mechanically to make sure that the cementing was properly done. The assembled insulator units are then given a flashover test similar to the test made on each porcelain part before assembly, except that, in the case of multipart insulators, the applied voltage is higher. The object of this test is to detect any defective insulators which may have passed the first test, as well as to detect pieces which may have been damaged while being assembled.

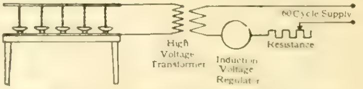


FIG. 1—CONTINUOUS FLASHOVER TEST CIRCUIT

RATING TESTS

It is frequently assumed by operating engineers that the design tests, on which the rating of an insulator is based, are made under service conditions by placing the insulator on the pin and cross arm with which it is to be used and connecting the pin to ground. Unfortunately early manufacturers did not make their tests in this way, but apparently placed the insulator on the test rack, with both terminals ungrounded, and measured the voltage by whatever method gave the highest results. Competition has forced all manufacturers to adopt the same methods, although the later designs of insulators are being rated more conservatively.

The voltage at which an insulator flashes over is reduced by grounding one terminal of the testing transformer and by the presence of grounded objects in the vicinity which will affect its electrostatic field. In practice, this is most noticeable when an insulator is mounted on a grounded metal cross-arm and the length of the pin is varied, as shown in Fig. 4. The insulator shown is made by a number of manufacturers, all of whom recommend that it be used on a 7 or 7.5 inch pin, yet the dry flashover value, as given in the various catalogs, ranges from 114 up to 145 kilovolts.

The manufacturers' data and the actual performance of a number of insulators which are in common use on 66 000 volt lines are compared in Table I. This test was made on a number of insulators and does not include all the later types, although it is fairly representative. The insulators were mounted on the pin recommended by the manufacturers and voltage measurements were made with a sphere gap, the figures in the table being the average of a number of tests. It will be observed that only one of these insulators will satisfy the A. I. E. E. rule which specifies the test for insulators to be used on outdoor apparatus, and even this insulator will have difficulty in passing the wet test, since the A. I. E. E. requirement is that the voltage must be withstood for ten seconds, whereas the value in the table is that which caused flashover as soon as applied.

The high frequency test is sometimes applied in investigating the design of insulators and also in determining the quality of the porcelain. Good porcelain will not be injured by high frequency unless it is continued for such a length of time that the piece is heated to an extreme temperature. The insulator shown in Fig. 5 was subjected to high frequency until the center of the piece became very hot and its expansion strained the outer rim, which was still cool, to such an amount that after the voltage had been applied for 20 minutes the piece burst with a loud report.

FIELD TESTS

On many lines, particularly those having old insulators, it is necessary to test the insulators for the purpose of detecting and replacing those which have deteriorated. These insulators have failed either because the material was defective in that it was porous, or contained internal strains which caused cracks to appear in service, or because the design of the insulator was defective, in that repeated changes in temperature set up strains which caused cracks. The insulators shown in Figs. 6 and 7 were undoubtedly cracked by strains set up by the hardware.

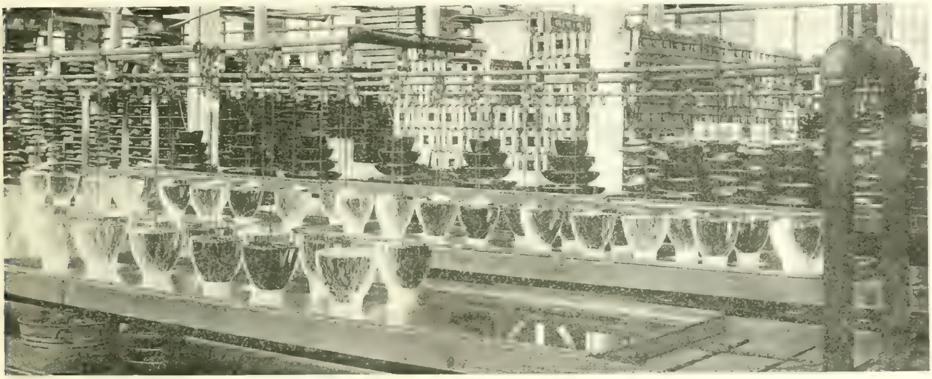


FIG. 2—INSULATOR CONES UNDER CONTINUOUS FLASHOVER TEST

Most insulator troubles are caused by cracks, which will soon absorb moisture from the cement and thus become conducting. The most satisfactory way of locating such defective insulators of the disc type has been by means of the megger. This method is easy and cheap, the only disadvantage being that the line which is to be tested must be taken out of service.

TABLE—I FLASHOVER VALUES IN KILOVOLTS OF SEVERAL 66 000 VOLT INSULATORS

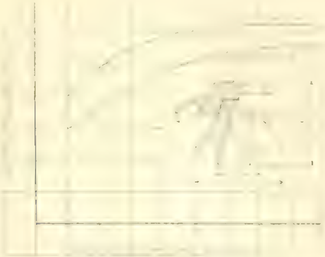
Sample	Catalog Data		Actual Performance		Required by A. I. E. E. Rules	
	Dry	Wet	Dry	Wet	Dry	Wet
A	165	130	170	135	151	133
B	205	135	190	130		
C	210	150	160	120		
D	195	140	155	130		
E	[illegible]		145	125		

The megger test cannot be applied to multipart pin insulators but, since the defects in these insulators usually occur in the head, some companies have been satisfied with a visual inspection at frequent intervals.

One operating company sends patrolmen over the line with field glasses to inspect the insulators and has found it possible to locate most of the defective ones in this way. If the line is in service while this inspection is being made, the patrolmen will frequently be able to detect bad insulators by their noise.

The "buzz-stick" method, which was developed by Mr. T. F. Johnson of Atlanta, is used on live insulators. This test is made by using a forked stick to short-circuit each unit of the insulator. If the unit is good, a spark will be drawn from the end of the short-circuiting fork, whereas if the unit is defective the potential will be the same on both sides of the unit and no spark will be drawn. On account of the danger of causing an arc if a number of the units should be bad and the remaining good one short-circuited in test, it is customary first to "feel out" the insulator. The method of performing the "feeling out" and the "shorting out" process is shown in Fig. 9 and needs little explanation. The buzz stick is brought close to the line wire and the sound of the spark is noted. The stick is then placed between the first and second units where the sound should be somewhat weaker. The sound will continue to get weaker as the stick is moved toward the ground end of the insulator, until the last two or three units are reached, when it will again begin to increase. After the insulator has been felt out, the short-circuiting fork is used to determine which units are bad, but if the feeling out process has shown that several units are questionable, the short-circuiting process is usually omitted and the whole string of insulators removed. In testing multipart pin insulators it is sometimes necessary to use two sticks, although one stick is sufficient for suspension units.

[illegible]



[illegible] varying the length of insulator pin. Insulator is mounted on grounded metal pin with line wire tied into head.

The spark coil method of testing insulators, particularly those of the disc type, has recently been introduced. Like the megger test it must be made on a dead line, which is not a real disadvantage inasmuch as the testing and replacing of the defective units can be done at the same time, so that the line does not need to be out of service much longer than would be necessary for the replacement of the bad insulators. This device is illustrated in Fig. 10. The entire equipment is placed on the pole which carries the testing fork and it is therefore unnecessary to have long leads between the testing fork and the ground. This is considered quite a safety feature, where several circuits may be located on the same structure. In applying this test the fork is placed around the insulator and the primary circuit of the induction coil is closed. If the insulator is bad, a spark will be shown at the spark gap, which may consist of an ordinary gas engine spark plug. It is difficult to adjust the gap so that it will not spark across while a good insulator is being tested and for this reason the practicability of this method of testing is doubtful.

[illegible]

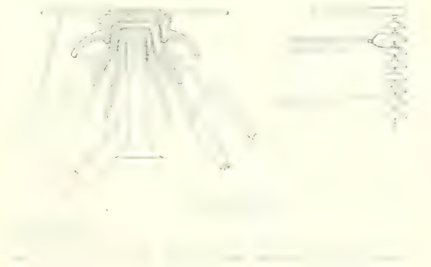
[illegible] Due to poor design of porcelain and hardware.

Another well-known method of testing is by the use of a pair of wireless telephone receivers, one terminal of which is connected to an antenna and the other terminal to the ground. A defective insulator gives off a peculiar scratching noise, which may be heard in the receivers. This method is quite satisfactory when used on wooden pole lines of 44 000 volts and above, but is somewhat hard to apply when used on 22 000 or 33 000 volt lines, particularly if there is a ground wire running up each pole. The presence of a telephone line below the power line also makes it difficult to hear any defective insulators and it is therefore some times necessary to use a long bamboo fishing rod to support the antenna above the telephone line. This puts the antenna dangerously close to the power wires and is not to be recommended. This test is difficult to apply because static discharges from other causes such as loose pins, give false readings and it has been found that an unskilled tester cannot be relied upon.

[illegible]

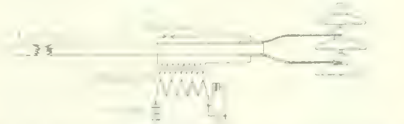
[illegible]

Several operating companies have tested insulators by means of high voltage at 60 cycles or by high frequency, using a portable testing outfit run by a gasoline engine. At least one line was tested with the insulators in place and other lines have been tested by removing the insulators and taking them to a convenient point, but both methods seem to be unnecessarily expensive.



One company has used a high frequency oscillator for this test and has found that the oscillator destroyed an enormous percentage of the discs which had been in service. Such a procedure is hardly justifiable, because undoubtedly some insulators were rejected which would still give good service for several years. Of course, when insulators are being tested at the factory the test should be made so severe that no defective insulators can escape detection, but after the insulators have been placed on the line, it is not necessary to remove them until they have become defective.

It is now good practice to use several more discs than is actually necessary on suspension type insulators so as to allow several of them to become defective without endangering service, and if the line is tested frequently enough, either by megger or "buzz-stick", there is no reason for interruption of service due to insulator failures. With present day insulators, which are not subject to an extreme depreciation, a test made once every two, three or even four years, may be sufficient, although with some of the old insulators which are still in service it is essential to make a test twice a year.



[illegible]

The Step Induction Regulator

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THE STEP induction regulator is similar to the usual step-type regulator in that the variation in voltage is obtained by cutting in or cutting out portions of the windings of a regulating transformer. However, instead of transferring abruptly from tap to tap, and obtaining only a comparatively few operating voltages, the transfer from tap to tap is made by means of a small induction regulator and any operating voltage is obtainable.

The step induction regulator consists essentially of a regulating autotransformer with a number of equally spaced taps, a double selector switch, a transfer switch and a small induction regulator with two separate, variable-voltage windings, each of which has a maximum voltage equal to one-half of the voltage between taps of the regulating transformer.

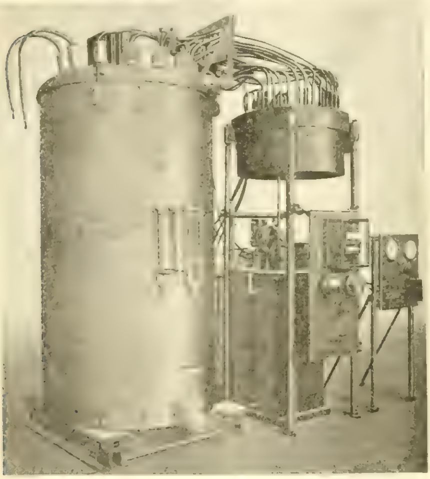

FIG. 1—FRONT VIEW OF STEP INDUCTION REGULATOR
Complete with series transformer and control panel.

The small induction regulator, selector switch and transfer switch of the step induction regulator are geared together, the relative time of operation of the switches being so arranged that a continuous rotation of the regulator shaft gives the entire range in voltage in a smooth curve similar to that obtained with large induction regulators.

The essential parts of a step induction regulator of the simplest form are shown diagrammatically in Fig. 3. In order that voltage curves may be shown, and the operation more easily explained, definite voltages have been assumed. The primary of the regulating autotransformer is connected across a 100 volt line. The 60 volt series winding is divided into six equal parts, so that seven voltages from 100 to 160 are available in ten volt steps. The primary of the induction regulator is also connected across the line. Each of the two secondary windings M to A and B to N is wound to give five volts, when the induction regulator is in a maximum voltage position. The transfer switch is shown in the diagram as a simple two contact drum switch. It is operated by the regulator shaft and connects the line lead L to coil lead A during one-half revolution of the shaft, and to coil lead B during the other half revolution. The switching is so timed that the transfer from A to B or from B to A is made when the voltage across coils AM and BN is at a maximum. The selector switch is represented in the diagram as a two-arm dial switch. One contact arm connects M alternately to contacts *1-3-5* and *7*, and the other arm connects N alternatively to contacts *2-4* and *6*. The selector switch is geared to the induction regulator in such a way that one turn of the regulator shaft gradually moves each arm from one contact to the next. The arms are so arranged however, that when one arm is located centrally on a contact connecting to any tap, the other arm is midway between two contacts which connect to the adjacent taps. In the particular case assumed in Fig. 3, the rotor of the induction regulator must make three complete turns to change the load voltage from 100 to 160 volts. The heavy curve in Fig. 4 shows the load voltage for all positions of the rotor shaft. Fig. 3 shows the various parts in the position

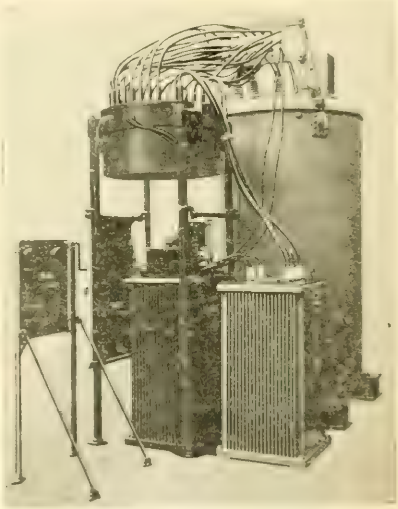

FIG. 2—REAR VIEW OF STEP INDUCTION REGULATOR SHOWN IN FIG. 1

they assume for the 105 volt point, which is one of the points at which the line lead *L* is transferred from *A* to *B*. At this point the voltage from *O* to *A* and from *O* to *B* would be the same even if the leads *A* and *B* were not joined by the transfer switch. The voltage from *O* to *A* is made up of the 100 volts from *O* to *1* plus the five volts of the coil *M* to *A*. The voltage from *O* to *B* is made up of the 110 volts from *0* to *2* minus the five volts of the coil *N* to *B*. Since the voltage of the points *A* and *B* is the same at these transfer points, there is practically no burning or flashing of the contacts when *A* and *B* are joined for an instant as the line *L* is transferred from one point to the other. The curve *D* in Fig. 4 shows the voltage which would be obtained from *O* to *A* if *M* were connected to tap *1* while the induction regulator made three turns. The voltage would alternate from a maximum of 105 to a minimum of 95 and the curve would follow approximately a sine curve as shown. Curves *F*. *H* and *J* are similar curves which would be obtained if *M* were connected respectively to taps *3*, *5* and *7*.

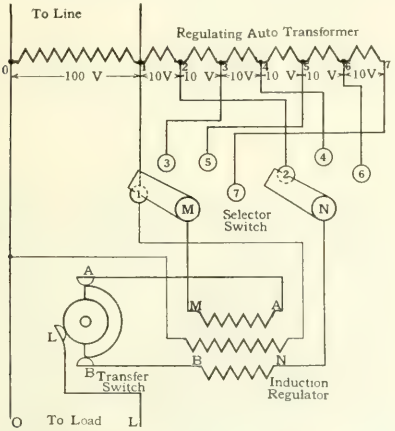

FIG. 3—CONNECTIONS OF ESSENTIAL PARTS OF A STEP INDUCTION REGULATOR

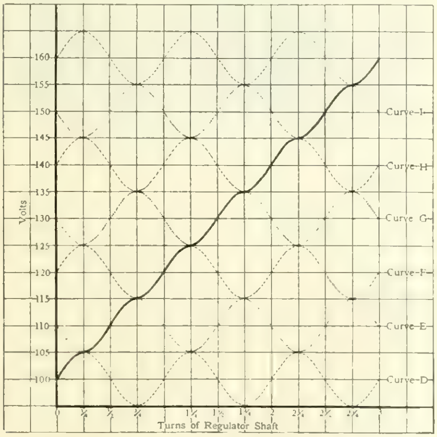

FIG. 4—LOAD VOLTAGE CURVES FOR ALL POSITIONS OF THE ROTOR

Curve *E* shows a similar curve of the voltage from *O* to *B*, assuming *N* connected to tap *2* during three turns of the rotor shaft. Curves *G* and *I* show similar curves with *N* connected respectively to taps *4* and *6*.

For the 100 volt point, the transfer switch would be in a position 90 degrees counter clockwise from the position shown in Fig. 3, and the voltage of the coil *AM* would be zero. As the regulator shaft with the transfer switch turns 90 degrees to the position shown, the voltage of the coil *MA* increases from 0 to 5 volts and the load voltage increases from 100 to 105, following the curve *D*. Instead of farther following the curve *D*, the line lead *L* is transferred to *B* and the load voltage therefore follows the curve *E* from 105 to 115 volts while the rotor turns from the one-fourth to the three-fourths turn position. *L* is then transferred back to the lead *A* but the lead *M* has been changed in the meantime by the selector switch from tap *1* to tap *3*, so that further motion from the three-fourths to the one and one-fourth turn position increases the load voltage from 115 to 125 along the curve *F*. By successively transferring from one regulator coil to the other and by selecting the proper tap by means of the selector switch, the entire range in voltage is obtained along the curve as shown by the heavy line in Fig. 4.

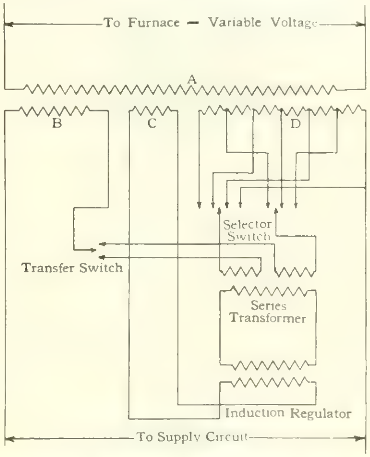

FIG. 5—CONNECTIONS OF ELECTRIC FURNACE REGULATING EQUIPMENT

The following points regarding the operation and performance of the step induction regulator are worthy of notice:—

1—The voltage between the transfer switch drum and the contact *A* or *B* is always zero just as the drum makes or breaks contact with either of these points. As a result the selector switch is practically free from burning or arcing.

2—The selector switch arms always move on or off the various contacts when there is no current flowing, so that there is no arcing or burning on the contacts of the selector switch.

3—Since the various switches are all geared to the small induction regulator, the entire outfit can be oper-

and not controlled as easily as a standard induction regulator.

4—The kv-a. capacity of the induction regulator is small in comparison with the kv-a rating of the regulating transformer. The small induction regulator must have a capacity equal to only one-half the capacity of a section of the winding between two adjacent taps of the regulating transformer. As a result the total exciting kv-a. required for the step induction regulator is very much less than that required for an induction regulator of equal rating.

[illegible]

The power-factor of the step induction regulator is therefore considerably higher than that of an induction regulator of the same rating.

5—All high-voltage windings of a step induction regulator are essentially transformer windings and are comparatively easy to insulate. The windings of an induction regulator are essentially motor windings, and are more difficult to insulate for the higher voltages. The transformer type of winding is also more easily braced to withstand the stresses due to short-circuits than is any other type of winding. For these reasons, step induction regulators are peculiarly adapted for large high-voltage circuits.

[illegible]
Selector switch is mounted inside of transformer tank.

The step induction regulator is adapted for at least three distinct classes of service; for controlling the voltage of electric furnaces, for high-voltage testing transformers, and for large high-voltage transmission systems. Fig. 5 shows a schematic diagram of connections for a furnace regulating outfit. The main transformer has a secondary winding *A* designed for the maximum current and voltage required by the furnace; *B* is the primary winding which, when connected directly across the supply circuit, produces in the secondary winding the maximum voltage required by the furnace; *D* is an additional primary winding which is divided into a convenient number of equal parts by taps, which are brought out to the selector switch.

[illegible]

By means of the small regulator, selector and transfer switches, a gradually increasing portion of the coil *D* is in effect connected in series with coil *B* across the line. As the number of turns of the total effective primary winding is thus gradually increased, the voltage per turn of the transformer windings is gradually decreased, and as a result the secondary voltage to the furnace is also decreased. The auxiliary winding *C*, for exciting the small induction regulator, is required only when the secondary voltage is too low or the line voltage is too high to be used conveniently for exciting the induction regulator. Usually, instead of putting the two equal voltage coils on the induction regulator as shown in Fig. 3, a series transformer with two equal secondary windings is used. The voltage of the series transformer is controlled by the small regulator, so that in effect the series transformer may be considered a part of the induction regulator. A series transformer is used in order that the two series windings may be insulated more satisfactorily. These coils must be insulated for the line voltage and it is difficult to insulate a small regulator for the line voltage usually used for this service. Since the two series coils are used alternately, each must be of sufficient capacity to take care of the full output of the small induction regulator. A larger regulator frame must therefore be used when the two windings are placed in the regulator than when only a single secondary winding is used for exciting the series transformer.

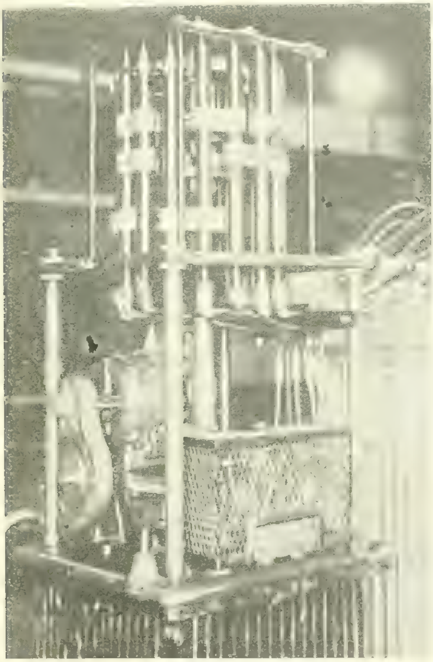

FIG. 9—DRY-TYPE SELECTOR AND TRANSFER SWITCH
Mounted on top of a small induction regulator.

A 1100 kv-a., 25 cycle, 14 500 volt step induction furnace regulating outfit, complete with control and meter panels, is shown in Figs. 1, 2 and 6. The primary of the main transformer consists of two equal sections, one of which is divided into 22 equal parts by taps which are brought out through the cover for connecting to the selector switch. A voltage range of from 40 to 80 volts is obtained on the secondary. The selector and transfer switches are of the oil-immersed type, and are mounted on a pipe frame directly over the 25 kv-a. induction regulator. The series transformer is shown just behind the induction regulator in Fig. 6.

A 400 kv-a., 25 cycle, 12 000 volt, furnace regulating outfit is shown in Fig. 7. A secondary voltage range of from 60 to 120 volts or from 120 to 240 volts can be obtained. In order that the taps need not be brought out through the transformer cover, the selector switch is mounted inside the transformer tank where it serves also as a terminal board for the taps and leads. This procedure simplifies the external wiring, and is advisable where the low-tension leads do not take up so much space as to make it impossible. Of course, a separately-mounted selector switch is more accessible for inspection and repairs, but since there is absolutely no arcing or burning on this switch there is no reason why, if substantially constructed, it should not operate for a considerable time without being inspected.

In some cases the step induction regulator can be built economically for very small outputs. This is particularly the case where very large currents at low frequencies are required. A dry-type selector and transfer switch is shown in Fig. 9 mounted on top of a small induction regulator for use with a 60 kv-a., 25 cycle, 2200 volt furnace transformer. This outfit gives a voltage range of from 10 to 30 volts. No series transformer is used, as both variable voltage series windings are provided on the induction regulator.

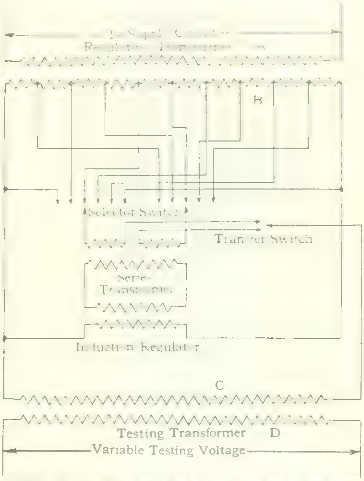

FIG. 10—CONNECTIONS FOR CONTROLLING [illegible]
[illegible]

The connections commonly used for controlling the voltage of a high-voltage testing outfit by means of a step induction regulator, are as shown in Fig. 10. The regulating transformer has a primary winding *A* suitably wound for the supply voltage. The secondary winding *B* is wound for a voltage the same as that of the low-tension winding *C* of the testing transformer. The entire winding *B* is divided into a convenient number of equal parts by taps, which connect to the selector switch. The induction regulator, series transformer, selector and transfer switches operate in the same way, as previously described, to impress an adjustable voltage on the low tension side of the testing transformer.

The advantage of this type of regulator for controlling high-voltage testing transformers is that the test voltage can be varied from zero to a maximum in an infinite number of steps, the same as if a large induction regulator were used, but due to the small capacity of the induction regulator, it introduces only a small reactance in series with the testing circuit and, therefore, causes less voltage-wave distortion and less danger of producing resonance than would be the case if the entire range in voltage was obtained from a large induction regulator.

An induction regulator with selector and transfer switch which has been used with a number of 200 kv-a., high-voltage, testing transformers is shown in Fig. 11. The transfer and selector switches are of the dry type and are designed for a maximum voltage of 2200 volts.

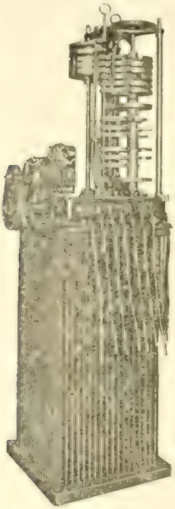

FIG. 11—INDUCTION REGULATOR EQUIPPED WITH DRY TYPE TRANSFER AND SELECTOR SWITCHES

To control the voltage of 200 kv-a, high-voltage testing transformers.

A 1000 kv-a., 750 000 volt, testing transformer has been designed to be controlled by the regulating outfit shown in Fig. 8.

The voltage conditions which must be taken care of by voltage regulators on large power systems are so varied that it is difficult to establish any rules which can be followed in determining the type of regulator best suited for a given service. The induction regulator is used almost exclusively on small, comparatively low-voltage circuits. However, the step induction regulator can be used economically in a great many cases, particularly on the larger, high-voltage circuits. This regulator is particularly applicable where considerable voltage variation is required, but where the voltage adjustments need not be made at too frequent intervals. The connections of one phase of a three-phase regulator are given in Fig. 12. *A* and *C* are the exciting and series windings respectively, of a regulating autotransformer. *B* is an auxiliary winding on the autotransformer for exciting the induction regulator. The series transformer has a double secondary winding.

The regulating autotransformer induction regulator and series transformer may be either single or polyphase. If they are single-phase, each set may be operated independently as a single-phase regulator or the three sets may be operated by one motor as a poly-phase regulator.

It is advisable to consider the regulator at the time the main power transformers are built because auxiliary windings for the regulator can frequently be provided on the main transformers, at a considerable saving. Since this type of regulator permits so many variations, it is well to make a careful study of each application. Sometimes it is advisable to use additional series transformers to reduce the current on the selector and transfer switches.

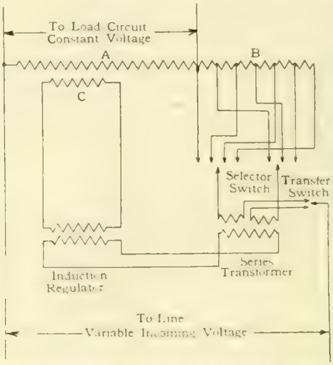

FIG. 12—CONNECTIONS FOR ONE-PHASE OF A THREE-PHASE REGULATOR

The chief advantages of the step induction regulator are:—High efficiency, high power-factor, reliability of insulation on high-voltage circuits, and ability to withstand heavy short-circuits on the line. Another advantage is that it can be arranged to be disconnected easily from the line without interrupting the service. This cannot be done with a polyphase induction regulator, because this type of regulator changes the voltage by shifting the phase of the series coils and not by changing the voltage of the series coils. It is, therefore, impossible to short-circuit the series winding of a polyphase induction regulator in any position of the rotor. The step induction regulator, even when using a small, three-phase, induction regulator, can always be so designed that the voltage across the series windings can be brought to zero and short-circuited and the regulator then cut off the line without opening the main supply circuit.

Interconnection of Power Systems

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THE INTERCONNECTION of power systems to reduce the investment in reserve capacity, lower generating costs and obtain greater continuity of service is steadily increasing. To obtain satisfactory operation, however, there are many details which must be given careful attention. The most important of these are:—

1—The selection of switching equipment with adequate rupturing capacity.

2—The use of tie lines having ample synchronizing power to hold the systems in parallel.

3—Relay protective systems arranged so that a defective section is quickly disconnected.

4—Voltage conditions studied with regard to the flow of wattless currents, both under maximum and minimum load conditions, and with power flowing in both directions.

The parallel operation of two generating stations is similar to that of two generators in the same station, the only difference being the impedance of the tie lines. The division of load between the two plants will depend entirely on the supply of energy to the prime movers and not on the voltage adjustment. If, however, the voltages are unequal, there is an unequal division of the reactive component of the load currents, the plant with the higher voltage taking more of the reactive component, thus equalizing the voltages at the paralleling point.

By proper voltage adjustments, the plant which furnishes power to the tie line may be made to supply the reactive component associated with that power, under which condition the difference in voltage at the two busses will vary with the load on the line, being zero at no load and a maximum when maximum load is being transmitted. Generally this method of operation produces too wide a range of voltage at the station bus for satisfactory service. However, by varying the magnitude and sign of the reactive component transmitted, it is possible to maintain any required voltage difference between the two plants. For any given voltage difference, there is a certain load which, with the reactive component associated with it, will absorb that voltage difference. When the power transmitted is less, it is necessary to set up a reactive current between two stations, which will lower the power-factor of the transmitting station and raise the power-factor of the receiving station. When the power transmitted is more than the given value, the reactive current must be in the opposite phase, and have the opposite effect on the power-factors of the two stations. In order to have the same voltage at both stations, the reactive current must always lead the voltage of the transmitting station, and increases as the load increases. This means that the receiving station not only must supply all of the reactive current associated with the load received from the other station, but must also supply a certain amount of reactive current to the line in order to hold up the bus voltage.

When it is necessary to maintain the same bus voltage at both stations, the reactive current may develop into an item of considerable cost. For this reason, it is desirable to reduce it as much as possible. This can be done in the following ways:—

a—By varying the voltage at either end of the tie line as the load varies, using,—

1—Taps on transformers.
2—Synchronous boosters.
3—Induction regulator.
4—Step induction regulator.

b—By varying the impedance of the tie line as the load varies.

To illustrate the merits of the various schemes, a definite problem will be worked out, taking as an example the tie between the Chester and Schuylkill plants of the Philadelphia Electric Company.

The Chester Station (*A* Fig. 1) has a capacity of 60 000 kv-a. and generates at three-phase, 60 cycles, 13 200 volts. The Schuylkill Station (*B* Fig. 1) has a capacity of 100 000 kv-a., three-phase, 60 cycles, 13 200 volts. There are two 66 000 volt tie lines. Each line is 76 000 feet long, and the conductors are 2/0 copper, spaced six feet apart. For each line there is a step-up and step-down transformer bank, each bank consisting of three 5000 kv-a., single-phase, 60 cycle, 13 200/66 000 volt transformers having $IR = 0.59$ percent and $IX = 4$ percent. These transformers have a maximum rating of 6250 kv-a.

Example 1—Suppose the voltage at $B = 13\,800$ volts, and it is desired to transmit 15 000 kw, at 85 percent power-factor by tie line from *A* to *B*. What must the voltage be at *A*?

Impedance of one bank of three 5000 *Kv-a. transformers* $= 0.069 + j0.467$ *in* 13 200 *volt terms.*

Impedance per mile of line $= 0.42 + j0.77$

Impedance per line $= 6.1 + j11.1$ *in* 66 000 *volt terms* $= 0.244 + j0.44$ *in* 13 200 *volt terms.*

Total impedance of line, step-up and step-down transformer $= 0.244 + j0.44 + 2\,(0.069 + j0.467) = 0.38 + j1.38.$

Current per line $= 630 - j390$

Drop per line $= (630 - j390)\ (0.38 + j1.38) = 777 + j722$

Voltage at station A $= \frac{13\,800}{\sqrt{3}} + 777 + j722 = 8777 + j722$

R m s value at station A $= \sqrt{3} \times \sqrt{8777^2 + 722^2} = 8780 \times \sqrt{3} = 15\,200$

Example 2—Suppose with a voltage at *B* of 13 800 volts it is desired to transmit 15 000 kw per line from *B* to *A*. What is the voltage at *A*?

Drop per line $= (630 - j390)\ (0.38 + j1.38) = 777 + j722.$

Voltage at station A $= \frac{13\,800}{\sqrt{3}} - 777 - j722 = 7223 - j722.$

R m s. voltage $= \sqrt{3} \times \sqrt{7223^2 + 722^2} = 12\,500$

Example 3—If 13 800 volts is maintained at both *A* and [illegible] to be transmitted from A to B what is the wattless current transmitted from A to B?

Let c = the wattless current per line.

[illegible] 13 800 [illegible] 8000 volts, per line.

Voltage at B = 8000 − (630 + jc) (0.38 + j1.38) = [illegible]

[illegible]

$$c = \frac{-22\,081 + 22\,630}{4.08}$$ [illegible]

Wattless kv-a [illegible] / 1000

Station A will, therefore, have to supply 3200 leading reactive kv-a. per line.

If the load power-factor is 85 percent, the lagging reactive kv-a. corresponding to 15 000 kw. is 9350 kv-a.

The generators at B will, therefore, have to supply 9350 + 3200 = 12 550 Kv-a lagging per line, in addition to the reactive kv-a. corresponding to their share of the load. If they are unable to do this, it will be necessary to install synchronous condensers of rating corresponding to 12 550 kv-a. per line.

Example 4—Suppose it is permissible to run A at 14 300 volts, the wattless current is reduced.

Let c = wattless current per line

[illegible]

Fig. 1—[illegible] Chester and Schuylkill power plants

Hence the current will be 71 amperes lagging and reactive kv-a. = 1700. If synchronous condensers are used, they would require a rating per line = 9350 − 1700 = 7350 *kv-a.*

To transfer power in both directions, with a voltage difference not exceeding 500 volts between the two generating voltages, it is necessary to have about 15 000 kv-a. in synchronous condenser capacity at each end of the line. This would mean a first cost for equipment of about \$150 000. Both on the grounds of first cost, and cost of losses, the synchronous condenser is not as favorable as the alternatives given below. The losses at full load for a 7500 kv-a. condenser are about 290 kw.

From *Example 4*, we see that changing the voltage at A from 13 800 to 14 300 volts, changes the wattless current from 134 amperes leading to 71 lagging, while some intermediate voltage would require no wattless current. When there are transformers in the tie line, this adjustment of voltage can be done by varying the taps on the transformer. The taps can be changed under no-load conditions, without any special equipment, but if it is desired to change under load, it is necessary to use oil circuit breakers and preventive autotransformers. Such a scheme is illustrated in Fig. 2. This cannot be made automatic, since a contact voltmeter cannot distinguish between a change in voltage caused by variations in the transmission line voltages, and that caused by a short-circuit or other disturbance on the line of momentary duration. These latter effects cause the apparatus first to raise and then to lower the voltage, causing the apparatus to function unnecessarily. In the present state of the art, circuit breakers must have a certain amount of time between operations under heavy load conditions to permit the venting of the accumulated gasses in the air chamber of the breaker.

From *Example 1*, the drop when transmitting 15 000 kw at 85 percent power-factor per line is 15 200 − 13 800 = 1400 volts, or $\frac{1400}{15\,200} \times 100$ = 9.2 percent.

If then the voltage at generating station A is kept constant, but nine percent voltage is added by some regulating equipment, the same thing would be accomplished. Station A could operate at constant voltage and the voltage regulating equipment would allow each line to transmit 15 000 kw at 85 percent power-factor. The regulating equipment would require a rating of 830 $\times \sqrt{3} \times \frac{9}{100} \times$ 13 800 = 1780 kv-a. This voltage regulating equipment could consist of several alternatives, as follows:—

Fig. 2—[illegible]

The circuit breakers are electrically interlocked and operated by a drum controller with nine positions.

Position	Breakers Closed	Position	Breakers Closed
1	1 and 6	6	4 and 3
2	1 and 2	7	4 and 6
3	2 and 6	8	5 and 4
4	3 and 2	9	5 and 6
5	3 and 6		

A synchronous booster set consists of a generator insulated for insertion in the line and driven by a synchronous motor. In the example, considered it might be, for instance, a 1780 kv-a., three-phase, 830 ampere, 1242 volt, 85 percent power-factor generator insulated for insertion in the 13 800 volt line, and driven by a 13 800 volt motor large enough to drive the booster and also to give a corrective kv-a. as well. This set would be furnished with a cradle so that the booster voltage can be adjusted to be in phase with the line voltage. It would have full load losses of about 200 kw, and two sets, one for each line, would cost about \$60 000 without installation costs. The objection in this case to a booster set is the difficulty of building a machine which will stand up under short-circuit conditions. If the machine is installed at station B a short-circuit at the booster would give about 30 times full-load current for instantaneous symmetrical values. Since the booster has a small rating, the windings have a relatively light cross section of copper and since the winding has to be insulated for 13 800 volts, it is very difficult to brace the coils to stand these currents.

A method of overcoming this defect would be to use a booster wound for a lower voltage, and to connect it into the line by a series transformer designed to saturate at fifty percent above normal voltage. The low-voltage machine will have end windings, with much shorter overhang and with less insulation on the copper, so the winding can be much better braced against distortion under short-circuit. The use of low-voltage will reduce the cost of the booster and partially compensate for the addition of a series transformer. The cost of a low-voltage booster and series transformer will be about fifteen percent greater than the high-voltage booster.

Instead of a synchronous booster, a three-phase induction regulator can be used. These regulators can be built for voltages up to 13 800 volts, and can be made oil-insulated self-cooling, oil-insulated water-cooled, or air blast. The oil-insulated types can be built for outdoor service. Generally speaking the cost of induction regulators should be less than synchronous boosters.

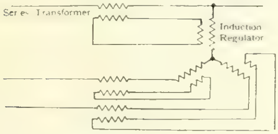

FIG. 3—SERIES TRANSFORMER USED IN CONNECTION WITH INDUCTION REGULATOR

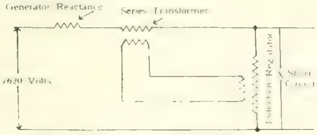

FIG. 4—EQUIVALENT OF ONE PHASE OF FIG. 3 WITH A SHORT CIRCUIT AT X

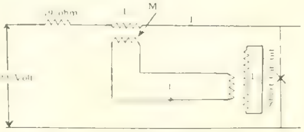

FIG. 5—REGULATOR VIRTUALLY SHUNTED OUT BY A SHORT CIRCUIT

As an induction regulator has a very low reactance, not much over one percent based on the rating of the feeder in which it is inserted, it is necessary to protect it with current limiting reactors where it is subject to heavy short-circuit currents. For instance, suppose a regulator was installed at station *B*, on the low-tension side of the step-down transformers. If station *B* has 100 000 kw capacity, at 11 percent reactance, this is equivalent to 2.07 percent on 18 750 kv-a. If the regulator has one percent reactance, it requires three percent current limiting reactors to limit the current to sixteen times full-load current in the case of a dead short-circuit. The windings of a large induction regulator used for the interconnection of generator plants should be braced similar to turbo-generator practice, and all mechanical details should be designed with short-circuit conditions in mind.

A 1750 kv-a., three-phase, 60 cycle, 13 600 volt induction regulator capable of nine percent buck or boost was installed early in the year at the step-down substation at Schuylkill station of the Philadelphia Electric Company for interconnection of the Chester and Schuylkill plants. The regulator has the following dimensions:—

Height	11 ft. 10 in.
Floor space	6 ft. 2⅝ in. by 6 ft. 2⅝ in.
Weight without oil	5[illegible] lbs.
Gallons oil	1570
Total losses	[illegible] kw

Just as in the case of the booster, a series transformer can be used in connection with an induction regulator, both to prevent insulating the secondary for line voltage and to reduce the short-circuit currents. As a further example, we shall consider such a case, with connections as shown in Fig. 3.

Example 5—At station B assume [illegible] three-phase, 60 cycle, induction regulator, capable of giving eight percent regulation on a three-phase, 830 ampere, 13 200 volt circuit in connection with a series transformer.

Station B = 100 000 kw; 11 percent [illegible]

Reactance in ohms = 0.192

Series transformer reactance $= \frac{1055}{\sqrt{3} \times 830} \times \frac{10}{100}$

$= j0.0735$

Induction regulator reactance $= \frac{1055}{\sqrt{3} \times 830} \times \frac{10}{100}$

$= j0.0735$

In the case of a short-circuit, the equivalent circuit per phase is shown in Fig. 4, which is equivalent to Fig. 5. Assuming that the series transformer saturates at 50 percent over-voltage, then at the point of saturation the voltage across the series transformer is $\frac{1055 \times 1.5}{\sqrt{3}} = 915$ *volts*.

The current in the series transformer and regulator is $\frac{915}{0.0735 + 0.0735} = 6230$ *amperes. The voltage drop from this current* $= 6230 \times (0.19 + 0.0735 + 0.0735) = 2100$ *volts. The net voltage to produce the current is* $7620 - 2100 = 5520$ *volts.*

Let

I_1 = the current in the primary of the series transformer.
I_2 = the current in the secondary of the series transformer and regulator.
L_1 = the self-inductance of the transformer primary.
L_2 = the self-inductance of the transformer secondary.
M_{12} = the mutual inductance of the series transformer.
L_0 = the leakage reactance of the regulator.

Then in the circuit consisting of the secondary of the series transformer and regulator—

$0 = j2\pi f\,(I_2 L_2 + I_2 L_0 - M_{12} I_1)$

Whence $I_2 = \frac{2\pi f \; M_{12} I_1}{2\pi f \; (L_2 + L_0)}$

In the case above,

$2\pi f M_{12} = 0.0625$ *ohm*
$2\pi f L_2 = 0.0625$ *ohm*
$2\pi f L_1 = 0.133$ *ohm*

The values were obtained from the design data of the series transformer.

$I_2 = \left(\frac{0.0625}{0.0625 + 0.0735}\right) I_1 = 0.45\, I_1$

Also

$5520 = j2\pi f\,(L_1 I_1 - M_{12} I_2) + 0.19 I_1$
$= j2\pi f\,(L_1 I_1 - M_{12} \times 0.45 I_1) + 0.19 I_1$

$I_1 =$

$\frac{5520}{2\pi f\,(L_1 - M_{12} \times 0.45) + 0.19} = \frac{5520}{0.133 - 0.0625 \times 0.45 + 0.19}$

$= \frac{5520}{0.3} = 18\,400$ *amperes*

$I_2 = 0.45 I_1 = 0.45 \times 18\,400 = 8300$ *amperes*

The total current in the secondary of the regulator = 8300 + 6230 = 14 530. This is 17.5 times full load current.

The cost of the regulator with the series transformer is approximately fifteen percent more than the high-voltage regulator.

A polyphase regulator adds a constant voltage to a circuit, but the phase angle can be varied from zero to 360 electrical degrees. In the case of the ordinary feeder, a variation from minimum buck through neutral or mid position to maximum boost is generally all that is necessary. In the case of interconnection, however, there may be two circuits which are unequally loaded, due to one being tapped and the other having no taps taken off. This will produce different phase angles in the two circuits. In that case, to get maximum loading it may be desired to place the regulators in a different position, as shown in Fig. 6.

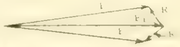

FIG. 6—POSITION OF REGULATORS TO OBTAIN MAXIMUM LOADING.

E_1 = Voltage at end of line 1.
E_2 = Voltage at end of line 2.
R_1 and R_2 = Regulator secondary voltages.
E_B = Voltage at station B.

Considerations like these require that regulators be capable of rotating the full 360 electrical degrees, so as to pass successively from buck, neutral, boost, second neutral, back to boost. Also in cases like these, it may be desired to know the exact position of the regulator. When the regulators are mounted outdoors, a position indicator is necessary. This is a modified reactive-factor meter. It has three voltage coils, spaced 120 degrees electrically. These are connected in star and supplied from a three-phase, 110 volt supply. A rotating field is produced and in this rotating field is pivoted a movable iron vane, magnetized by a stationary coil. This coil is energized from a potential transformer connected across the secondary on one phase of the regulator. The iron vane takes up a position where the zero of the rotating field occurs at same instant as zero of its own field. The pointer will follow through 360 degrees as the regulator is moved, and the dial can be calibrated in any way desired.

The last method of varying the voltage is by the use of a step induction regulator. This regulator is similar to the step-type regulator in that the variable voltage is obtained by cutting in or cutting out a portion of the series winding of a regulating transformer. However, instead of transferring abruptly from tap to tap, the transfer is made by means of two variable voltage coils on a series transformer, the voltage of which is varied by means of a small induction regulator.

In general, for interconnection the induction regulator is the simpler equipment for 13 200 volts and lower, but above this voltage, where transformers for both the primary and secondary of the induction regulator are necessary, the step induction regulator has the advantage of lower first cost.

As an alternative to varying the voltage, the impedance of the tie lines can be varied. As a leading current flowing over a reactance produces a rise in voltage, therefore an increase in the reactance will mean a reduced leading current for a given increase in voltage. This method, however, has limited application, as other conditions generally prevent the switching of tie lines or the insertion of additional reactance.

Tie Line Application for Induction Feeder Regulators

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THE USE of induction feeder regulators by central stations has increased materially during the past few years. The principal requirement has been for voltage regulation on distribution feeders, and it is only recently that their application has been broadened in an increasing variety of ways. For example, wherever a smooth variation in voltage is required, rather than the maintenance of a constant voltage, the induction regulator has found a wide field of usefulness. The following applications for induction regulators have been developed to date:—

1—To maintain a constant desired voltage at a given center of distribution on feeder circuits. This has been the most important application.

2—For the voltage control of testing transformers.

3—For controlling the voltage of electric furnaces. This application is practically new, as the use of very large furnaces has not been common until recently. Small electric furnaces and welding machines are generally controlled by the use of transformers with suitable taps.

4—To the alternating-current side of rotary converters to maintain a constant desired direct-current voltage. This application has been almost entirely superseded by the use of the booster-converter.

5—To transmission lines which supply power to interconnected loads, and operate as tie lines connecting two large power systems or stations in parallel.

The last named application is also the most recent, and presents some very interesting problems, both from the theoretical and manufacturing standpoint. An example is the recent installation by the Philadel-

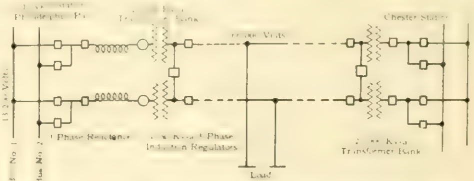

FIG. 1—A SINGLE LINE DIAGRAM OF THE PHILADELPHIA AND CHESTER TRANSMISSION SYSTEM

phia Electric Company of two large polyphase induction regulators for this purpose. This problem involved the paralleling of two generating stations, the Schuylkill power house at Philadelphia and the Chester station at Chester, which are connected by two lines about fourteen miles long, as shown in Fig. 1. The desired results in the way of voltage regulation could be obtained either by synchronous boosters equipped with a frame shifting device or by polyphase induction feeder regulators. The induction regulator was finally chosen for this service* because of its superiority over the synchronous booster in the following points:—simplicity, ruggedness and ability to resist short-circuit stresses, adaptibility to outdoor service and lower initial cost.

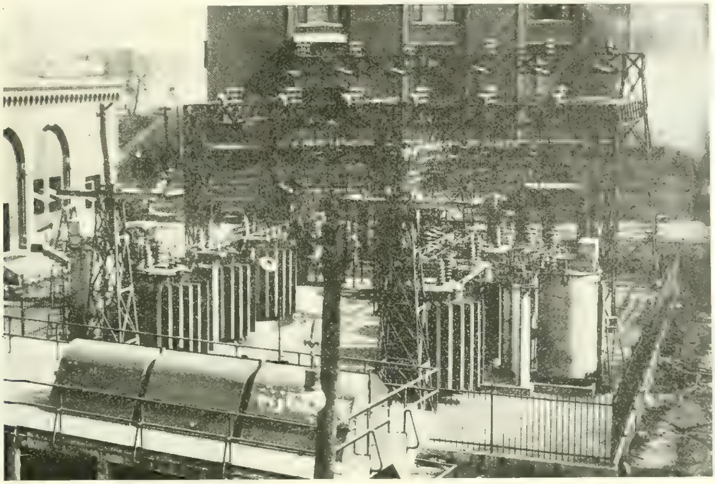

FIG. 2—THE 66 000 VOLT OUT-DOOR SUBSTATION AT PHILADELPHIA

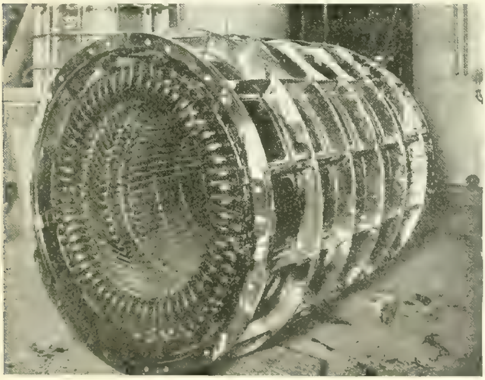

FIG. 3—BOTTOM VIEW OF REGULATOR STATOR
Showing the bracing of coil ends.

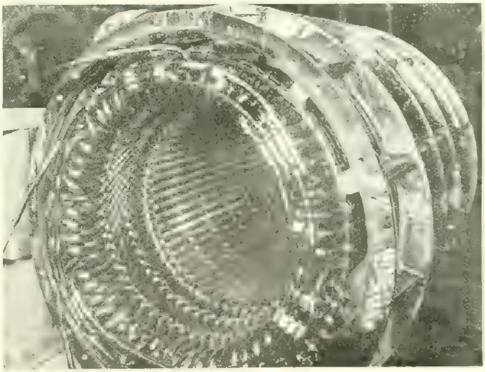

FIG. 4—TOP VIEW OF REGULATOR STATOR
Showing the bracing of coil ends.

These polyphase induction regulators are of particular interest, being by far the largest ever built. They are motor operated, water cooled, designed for outdoor service, and are rated as 1750 kv-a., three-phase, 60 cycles, 13 600 volts, nine percent regulation, and are arranged for use on a 20 000 kv-a. transmission circuit. It was necessary to construct the regulators so that they would be able to withstand very severe disturbances of either the line current or voltage. The ability of these machines to withstand heavy short-circuits was especially important, as heavy current surges are often experienced, and interruption of service on either of these two lines would be disastrous, on account of the important industrial plants that would be shut down. The regulators, therefore, have been built to withstand instantaneous currents as great as fifteen times the normal rating, and line reactances have been installed which limit the short-circuiting current to this

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*The application of this apparatus is also described by Mr. Raymond Bailey in the *Electrical World,* June 12, 1920.

value. The building of such large units under the circumstances presented a problem involving new features, both in the engineering design and factory construction. To load the two lines properly, it is necessary to know the phase relation of the regulator secondary voltages, their relation to each other and to the line voltages. To accomplish this, each regulator is equipped with a position indicator, consisting of a 360 degree power-factor meter, calibrated for this service. These position indicators, with the instruments for the two transmission lines, are mounted on the station switchboard near the regulator operating-motor control.

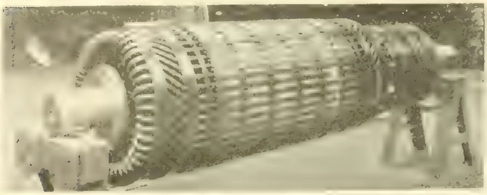
FIG. 5—REGULATOR ROTOR COMPLETE WITH SLIP RINGS

Figs. 3 and 4 show the stationary or primary winding. This winding was designed with the following main points considered:—

1—Employing the best class of insulation available.
2—Making the coil ends as short as possible, without interfering with the winding of the machine.
3—Bracing of the coil ends thoroughly to prevent distortion.

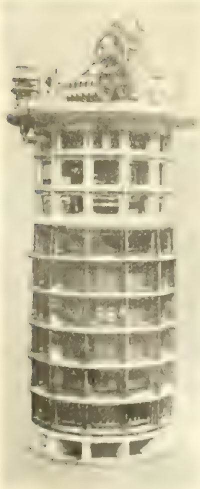
FIG. 6—COMPLETE REGULATOR REMOVED FROM TANK

The insulation employed on both stator and rotor on all parts embedded in the slots is A. I. E. E. class B-2. It consists chiefly of mica and is identical with that employed in standard turbogenerator construction.

To reduce the possibility of the distortion of the coil ends, it is necessary to keep the lengths of these ends a minimum. To do this, however, in coils insulated for this high voltage and fairly heavy current is not a simple design problem, on account of the difficulty of placing the coils in the slots if the ends are too short. Figs. 3, 4 and 5 show the rotor and stator windings.

The windings are held still more securely by proper bracing in all directions. The coil ends are reinforced by, and securely tied to, insulated steel rings, as illustrated. They are also packed between turns, so that both front and back sections of the winding receive the support of these bracing rings. In addition to the ring bracing, wedge shaped blocks are placed and tied firmly between coils to prevent lateral distortion. The wedges and packing are put in place as the winding progresses.

Perhaps one of the most interesting features in the design of this regulator is the use of slip ring contacts for the rotor winding. This method eliminates undesirable high voltage flexible leads around the rotor shaft and at the same time permits 360 degree movement of the rotor. In this way both a lagging and leading neutral position of the regulator secondary voltage is obtained.

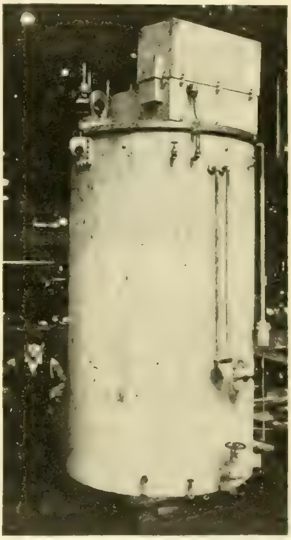
FIG. 7—1750 KV-A, THREE PHASE, 132 000 VOLTS, NINE PERCENT REGULATION, WATER COOLED INDUCTION REGULATOR
Complete with tank and outdoor hood.

A rather ingenious method has been employed to prevent serious damages to the important castings, gear housing, cover, etc., in case an abnormally severe short-circuit should develop. The forces set up under the conditions are so large that it was deemed desirable to take precaution against serious damage to these parts. Consequently, the regulator worm housing is equipped with bearing plates held in place by four bolts in such a manner as to permit movement of these plates through elongation of the bolts if sufficient stress is applied by the regulator rotor. It is calculated that the time required for these bolts to lengthen is sufficient for the protecting circuit breaker to open.

The complete regulator is shown in Fig. 7 with pipe connections for the cooling water and breather. The cooling coils are of copper tubing and are fastened into the top of the regulator tank.

Switching and Protection of Transmission Circuits—III

S. Q. Hayes

THE VARIOUS important constituents connected with transmission switching and protection having been discussed, some power systems both proposed and actual, will be considered to get a broader view point of the problems involved.

In connection with a proposed generating station that will ultimately contain fifteen 25 000 kv-a, vertical shaft waterwheel generators, some preliminary studies were made relative to the switching equipment, with the idea of placing the low-tension curcuit breakers, as well as the high-tension, out of doors.

The original installation of this plant is to comprise four, 25 000 kv-a, 12 kv, 60 cycle, three-phase maxiimun rated vertical shaft waterwheel generators with suitable exciters. The output of the first four units is to be transmitted at the generator voltage, 12 kv. to a large industrial plant in the neighborhood, a distance of about two miles, over four feeder circuits, each of 25 000 kv-a capacity. These feeders are to tie in with the present switching equipment at that plant which is now fed from a maximum rated turbo-generator of 70000 kv-a capacity and two 20 000 kv-a transformer banks, stepping down from 110 to 12 kv, fed from a large power transmission system.

It is quite probable that the two 20 000 kv-a transformer banks, with their equipment, that are now located near the steam station, will be moved to a point adjacent to the hydraulic plant and that two additional banks of the same capacity will be added. These four 20 000 kv-a transformer banks, with four 110 kv. lines of the same capacity, are to form the load for the next three units, but 25 000 kv-a transformer banks and lines may be used instead, to facilitate the employment of the unit system of switching. Energy will probably be delivered to the power transmission system mentioned above.

The disposal of the output of the final eight units is a more difficult problem to predetermine, but designs have been worked up on a basis of using four 50 000 kv-a transformer banks, each fed from two 25 000 kv-a generators, and each feeding a 50 000 kv-a line at a high voltage, such as 220 kv, and power will be delivered in large blocks to important industrial centers and power networks within a radius of two or three hundred miles.

It is likely that the generators will be of the outdoor design, with concrete stators, and there will be no roof over the portion of the power house containing the generators.

The complete ultimate plant is shown on the single line diagram of connections, Fig. 52. The parts contemplated for the first installation are shown within the dot and dash line, and these connections and the location indicated for the apparatus correspond closely with the actual mechanical location contemplated for the various devices.

With the first installation of four units, it is the intention to make the generator bus of 1200 amperes capacity in place of 2400; i. e. of the capacity of one generator in place of two. By doing this, the size of the bus circuit breakers would be the same as those for the generator and reactor circuits.

The rupturing capacity selected for the main circuit breakers, viz: 24 000 amperes at 12 kv has been based on the use of 1200 amperes, five percent reactors, connected to the bus as shown. These five percent reactors would permit 20 times normal current to flow, if the voltage were maintained on the bus. As the generators will have 20 to 25 percent reactance, and the bus will be sectionalized as indicated on the diagram, a circuit breaker with rupturing capacity of 24 000 amperes at 12 kv was considered amply safe on this system, with the method of operation to be utilized.

For the local service, an allowance of 5000 kv-a total has been made, based on two 1000 kv-a local service transformer banks, and three 1000 kv-a feeders. Local service reactors marked on the diagram as 250 amperes five percent would allow 5000 amperes to flow through one set of reactors to the local service bus. An electrical interlock will prevent the closing of the two service circuit breakers at the same time.

The first four units, as stated previously, will probably furnish power to a neighboring industrial plant, the neighboring feeders being marked *N-1, 2, 3,* and *4,* the generator circuit breakers being marked *G-1, 2, 3,* and *4,* the reactance breakers *R-1, 2, 3,* and *4.* Similar markings are used for the balance of the generator and reactor circuit breakers, the transformer circuit breakers and the line circuits. It is the intention to sectionalize the main bus in such a manner that only two generators can normally be connected to the same section, with the exception of the section to which units *5, 6,* and *7* are connected.

Each group of generators and neighboring feeders is provided with a total of three circuit breakers. One will be in the generator circuit, connecting the generator to a generator bus section. This in turn, is connected either to the neighboring feeder by a suitable circuit breaker or through a circuit breaker and a reactor to the main bus. Transformer circuit breakers *T1* to *T4* and feeder circuit breakers *N1* to *N4* are in the same horizontal row as generator circuit breakers *G1* to *G7* and reactor circuit breakers *R1* to *R7*; the relative order in in the same horizontal row being probably as indicated. The high-tension side of the transformer banks *1, 2, 3,* and *4*, connect through suitable circuit breakers also marked *T1*, *T2*, *T3*, and *T4*, and disconnecting switches to either of two 110 kv busses sectioned in the middle in such a manner that the four 110 kv outgoing feeders can be operated each from its own transformer bank if such a method of operation proves desirable.

The mechanical location of the generator bus sections will be such as to allow adjacent sections to be connected together through disconnecting switches, if operating conditions make this desirable. Such an arrangement will more readily allow a generator to be used with a feeder on either side of it without the reactor in the circuit. A complete generator ring bus with disconnecting switches on each side of each generator circuit could be formed in this manner, if wanted, but such a method of operation would be extremely dangerous, owing to the tremendous amount of energy concentrated on the bus bars.

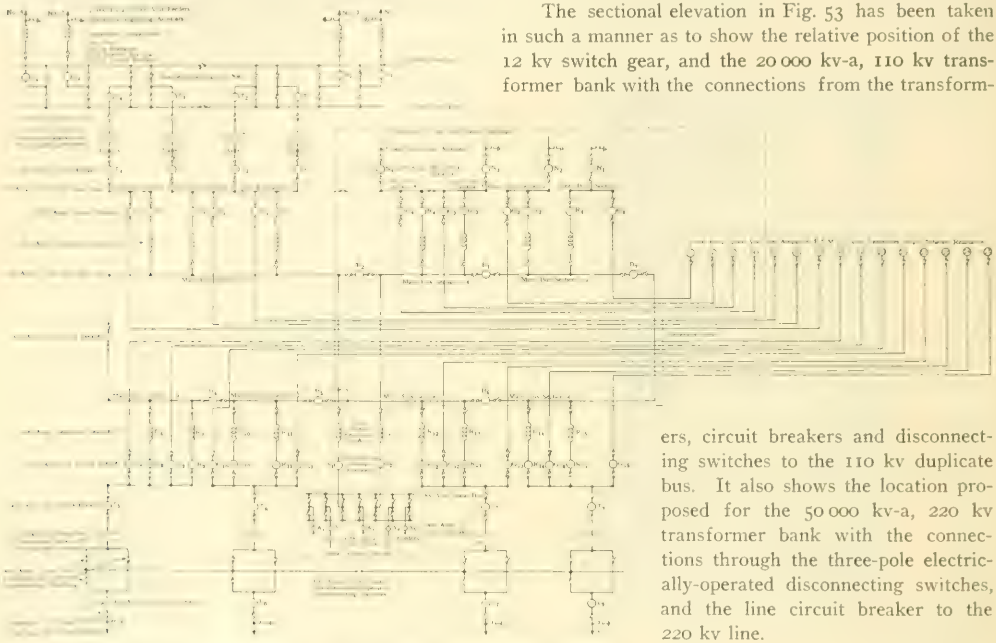

FIG. 52—PLAN OF A PROPOSED 375 000 KV-A HYDROELECTRIC POWER PLANT

Generators *8* and *9* will be used in furnishing energy through transformer circuit breakers No. 5 to a 50 000 kv-a transformer bank. Generators *10* and *11* in a similar manner will be used for furnishing energy through transformer circuit breaker No. 6 to a second 50 000 kv-a, 220 kv transformer bank. Generator *12* and *13*, *14* and *15* will similarly be used for transformer banks *7* and *8*. The local service will be taken off through local service reactors, one connected on either side of bus section circuit breaker No. 2.

Each of the 50 000 kv-a, 220 kv transformer banks with its outgoing line is provided on the high-tension side with four 400 amperes, 220 kv, three-pole, electrically-operated disconnecting switches and one 400 amperes, 220 kv, oil circuit breaker. One of these three pole disconnecting switches is used for isolating the oil circuit breaker from the high-tension line. The three remaining three-pole disconnecting switches are used in such a manner that the transformer bank can be connected directly to the line circuit breaker, and that the transformer bank or the line circuit breaker can be connected to the 220 kv bus. This 220 kv bus will be sectionalized in the middle by a three-pole electrically-operated disconnecting switch.

The sectional elevation in Fig. 53 has been taken in such a manner as to show the relative position of the 12 kv switch gear, and the 20 000 kv-a, 110 kv transformer bank with the connections from the transformers, circuit breakers and disconnecting switches to the 110 kv duplicate bus. It also shows the location proposed for the 50 000 kv-a, 220 kv transformer bank with the connections through the three-pole electrically-operated disconnecting switches, and the line circuit breaker to the 220 kv line.

The disconnecting switches utilized in the 110 kv circuits are of the suspended type with rigid insulators, and double throw switches are provided to facilitate connecting the transformer bank to either of the two sets of bus-bars. A different type of 110 kv switches may be employed, with all three poles mechanically controlled at the same time, the switch being of the vertical construction, instead of inverted, so that the switch blades would be above instead of below their insulators.

The disconnecting switches indicated in the 220 kv circuits have been shown of the three column type. The switch blade is arranged to move in a vertical plane, and all three poles will be controlled at the same time. These 220 kv switches are indicated as being mounted on a steel platform. The 220 kv switches used for sectionalizing the transfer bus will be mounted on the steel work of the tower construction. A common platform will be used for containing the three-pole, 220 kv switches in the outgoing line circuit, and the horn gaps of the 220 kv arresters.

The section shown in Fig. 54 has been taken through the 12 kv structure at the point to show all of the generator leads, which are run on steel structures mounted on porcelain insulators, each three-phase circuit being completely enclosed in a metal grill. The compartment marked vacant will probably be utilized for running the control and auxiliary leads. The leads are indicated as dropping down from the lead compartment through disconnecting switches into the 1200 ampere, 15 kv generator circuit breaker for circuit No. 15. The leads then pass back through other disconnecting switches to the generator bus. Potential transformers with their out door fuses are tapped from the circuits dropping down from the generator leads to the generator circuit breakers. The main bus-bars and the generator reactors, as well as the connections for the reactor circuit breaker are shown on this sectional view.

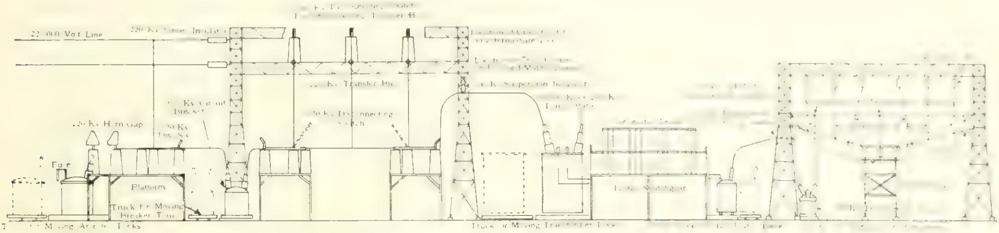

FIG 53 RELATIVE POSITION OF SWITCH GEAR AND TRANSFORMER BANKS
For the 110 kv system and the proposed 220 kv system

The plant just described is typical of an installation of large capacity with power all developed at one plant and with a fairly good idea of the probable future requirements, so that a comprehensive plan may be worked out at the start. Most power systems, however, are the result of a growth that has caused the linking together of plants originally distinct and the development of resources, wherever available to meet the constantly increasing demands for power. It is impossible in a brief article fully to describe all of the important power systems in the United States or even to attempt to list them. For the purpose of making clearer some of the problems connected with transmission, switching and protection, a few representative systems in different parts of the country will be described, showing how different plants tie into the same system, and how the relay equipments previously discussed can be utilized to cause the circuit breakers to function in such a way as to cut out defective sections or equipments.

As an example of a power system that has resulted from the tying together of numerous stations originally built for power transmission at different voltages, the system of the Montana Power Co., is typical. This Company has extensive power circuits which cover a large part of Montana extending from Havre through Great Falls to Butte and to Anaconda, a distance of approximately 320 miles. Its lines cover a territory approximately 200 miles east to west, 300 miles from north to south. This Company supplies power for the first electrified portion of the Chicago, Milwaukee & St. Paul Railroad in Montana from Avery, Idaho to Harlowton, Montana, a distance of 440 miles along the railroad.

The transmission lines of the Montana Power Company, are practically divided into three systems: 46 kv, 65 kv, and 100 kv. The 46 kv system shown in Fig. 55 is usually known as the Madison River system, the two main generating plants being Madison No. 1 and Madison No. 2. The generating equipments at Livingston and Billings are small and only serve to take care of local requirements. Madison No. 1 plant on the Madison River was completed in 1901, remodeled in 1907, and is of 2000 kw capacity. The Madison dam is located below Madison canyon, 60 miles southwest of Butte. A head of 110 feet is obtained for the two 1000 kw generators. Power plant No. 2, 7500 ft. below the dam, has four horizontal turbines of 2500 kw capacity. This plant was completed in 1906. The power generated is stepped up to 100 kv for transmission to Butte, ending at the Montana Street substation. From Montana Street Substation, a tie line is taken to the Great Falls substation, on Butte Hill. There also enters the Montana Street substation, an 11 000 volt line from the Big Hole plant (the first to supply power to Butte) located about 22 miles southwest of Butte on the Big Hole River. It was put in operation in 1898, transmitting power to Butte on a double circuit pole line. This plant contains four 750 kw horizontal shaft units.

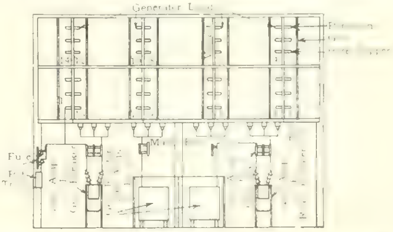

FIG. 54—GENERATOR LEADS IN THE 12 KV STRUCTURE

The 65 kv system shown in Fig. 56 is known as the Missouri River System and has its main generating stations at Canyon Ferry and Hauser Lake. The Canyon Ferry Plant on the Missouri River was completed in 1898 and enlarged in 1901. It operates at a head of 14 feet and contains ten 750 kv-a. horizontal shaft waterwheel units. The original transmission from this plant, was at 11 kv to the adjacent Helena district for lighting and power service. In 1901 duplicate 65 kv transmission lines were built into Butte.

The Hauser Lake plant, completed in 1911 and enlarged in 1914, operates under a head of 65 ft. It contains six 3000 kw horizontal shaft generators and the power is stepped up to 65 kv and transmitted by duplicate lines to a junction with the Canyon Ferry transmission lines at E. Helena and then by these lines to Butte and the Montana Power Company's general distributing systems. At the Missouri River substation on Butte Hill this system is tied into the others through a 2400 volt trunk line between the Missouri River substation and the Great Falls substation, a distance of approximately 1500 ft.

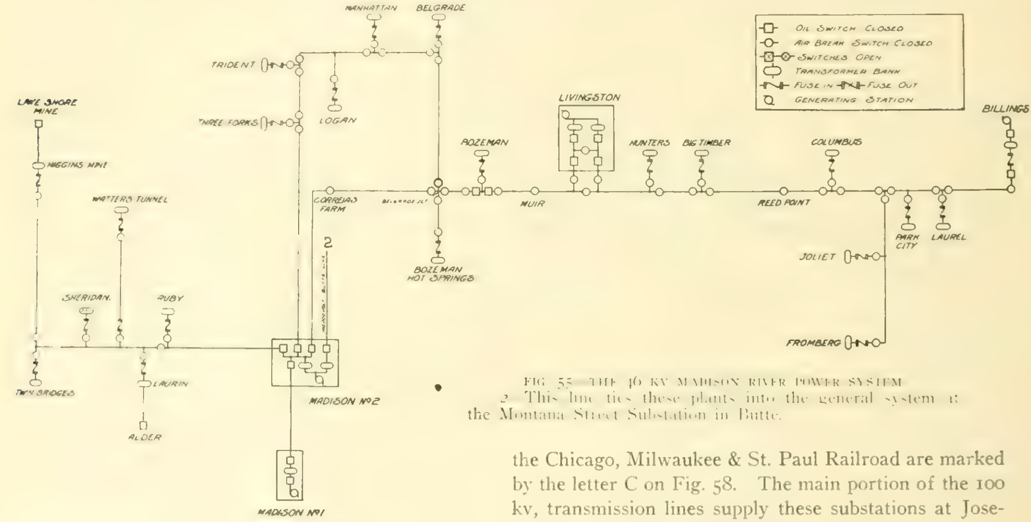

FIG. 55—THE 46 KV MADISON RIVER POWER SYSTEM

2 This line ties these plants into the general system at the Montana Street Substation in Butte.

The 100 [illegible] system, shown in Fig. 58 is known as the Montana Power System and is fed principally by the Rainbow, Volta and Holter plants. The Rainbow Plant on the Missouri River operates under a head of 112 ft. It was completed in 1910, and enlarged in 1916, and contains six 4200 kw horizontal units and two 5000 kw units. Power is stepped up to 110 kv for transmission to the large mining and smelting districts of Butte and Anaconda and to 50 kv for transmission to Hall, Lewistown, Sun River and the Choteau District, supplying light and power to many small communities and the coal mines of the Great Northern Railway at Stockett and Lehigh.

The plant at Black Eagle Falls operates under a head of 44 ft. with a capacity of 1300 kw, the power being used for a copper reduction works and the furnishing of energy to the City of Great Falls for the lighting and street railway system. Two plants on opposite sides of the river at Black Eagle Falls operate in parallel and also in parallel with the Rainbow plant.

The Great Falls generating station, operating under a head of 150 feet, was completed in 1916, and contains six sets of 10 000 kw vertical shaft water wheel generators, operating at 6600 volts with transformers stepping up to 110 kv. Power is transmitted over three high-tension lines to Two Dot; lines having a capacity of 15 000 kw, and a length of 102 miles serving the Chicago, Milwaukee & St. Paul Railroad. The Morel line, with a capacity of 30 000 kw and a length of 143 miles, serves the Chicago, Milwaukee & St. Paul at Morel, which is about at the middle of the 445 mile electrified line. This plant also supplies several smelting plants over a line about eight miles long.

The various substations on the electrified portion of the Chicago, Milwaukee & St. Paul Railroad are marked by the letter C on Fig. 58. The main portion of the 100 kv, transmission lines supply these substations at Josephine, Eustis, Piedmont, and Morel, and is also used at times for furnishing power to the railway substations at Ravenna, Primrose, Drexel and Avery, although normally these substations are supplied with power from Thompson Falls.

The generating plant at Thompson Falls, operating under a head of 50 feet on the Clark Branch of the Columbia River, was completed in 1916 and has a capacity of 30 000 kw. This plant primarily takes care of the Idaho or the Coeur d'Alene mining district.

The Holter Plant was completed in 1917 and operates under a head of 100 feet. It contains four 12 000 kv-a, 10 000 kw vertical shaft, water wheel three-phase, 60 cycle, 6600 volts, 150 r.p.m. generators, with four 16 000 kv-a. maximum rated O. I. W. C. indoor type, three phase transformers stepping up from 6.6 to 107 kv.

The Holter plant is one of the few modern hydro-electric stations using indoor type transformers and indoor switch gear for 100 kv service. Fig. 57 shows a section through this plant, the arrangement of which is typical for such an installation. The leads from the generators are taken through the generator low-tension circuit breakers to the 6.6 kv bus or through other circuit breakers directly to the low-tension side of the step up transformers. The leads from the high-tension side of the transformers are taken up through floor openings, where they are attached between insulators and then pass through choke coils and disconnecting switches to the high-tension circuit breakers and then to the bus. From the bus the leads pass to other disconnecting switches, circuit breakers and out through roof bushings. A grounding switch is located near these bushings for grounding the high-tension circuits. The electrolytic lightning arresters are located on the roof of the building.

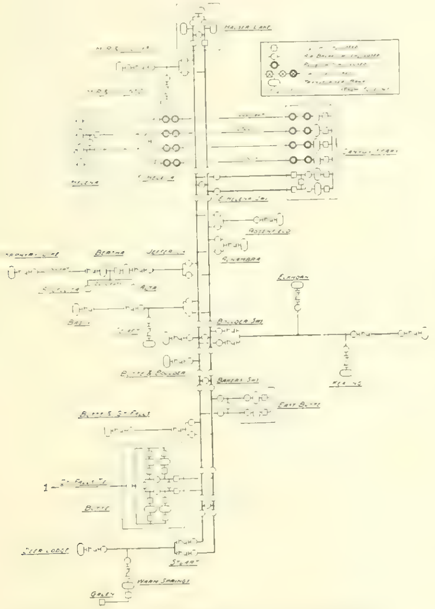

FIG. 56—THE 64 KV MISSOURI RIVER POWER SYSTEM
1—Tied into the general system here in Butte.

In 1916 the Montana Power Co., had 15 plants developing 230 000 hp, with 864 miles of high-tension line and 75 substations. At that time they also had under way the Holter Plant rated at 40 000 kw, which added to the plant then in operation, made a total of 211 450 kw. They had at that time undeveloped water sites aggregating 121 500 kw.

The proper relaying of a complicated network of transmission lines such as shown in Figs. 55, 56 and 58, has been treated in the June number in a rather general manner, and has been discussed in very considerable detail in an article by Mr. L. N. Crichton.* The main 100 000 volt system, shown in Fig. 58, is arranged in the form of a ring with the main generating stations at Volta (Great Falls) Rainbow and Holter, and the general scheme for the relaying of a ring system such as this, is covered by Fig. 38, page 267 of the June number of the JOURNAL. As pointed out in connection with the description accompanying Fig. 38, the setting of the relays is such as to facilitate the automatic sectionalizing of the line in case of trouble.

As far as the relaying is concerned, the ring system might be considered as starting at the Volta Plant passing to Two Dot, Loweth, Josephine, Eustis, Piedmont and Janney, all of these being substations supplying power to the Chicago, Milwaukee & St. Paul Railroad. The ring is closed through the substations at Janney and Morel which are also substations of the railway, with alternative paths back to the Volta station, one path passing through the Holter generating station, the other returning through the Anaconda substation, the Butte-Great Falls substation, the East Helena substation, and the Rainbow generating station.

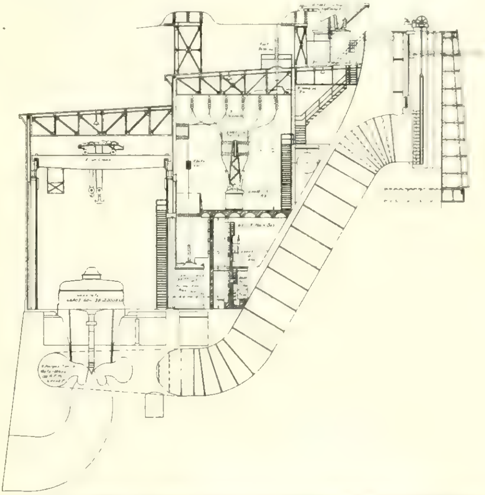

FIG. 57—CROSS-SECTION THROUGH GENERATOR AND SWITCHING ROOMS OF THE HOLTER POWER STATION

The relaying of the system is considerably complicated by the fact that the 46 000 volt system from the Madison River Division ties in at the Madison substation, and the 65 800 volt system ties in at the Butte substation.

As explained in connection with Fig. 43, p. 268 of the June number, the selective relaying of a ring system with cross connections can be considerably simplified by arranging to open automatically the circuit breakers in the cross tie connections shown in Fig. 43 at the letter *A*. To carry out the same idea on the Montana Power system, the cross connecting circuit from the Holter plant through East Helena and Townsend to Josephine, could have instantaneous automatic breakers at each end of the line so that in case of a system short-circuit, this cross connection would be opened automatically if it were carrying more than the normal energy flow.

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*In the JOURNAL, Vol. XIII, p. 339.

Tapped off from the main ring system is the series of substations of the Milwaukee Railroad from Avery through East Portal, Drexel, Tarkio, Primrose, Ravenna and Gold Creek to the tie-in point on the Morel line. Under normal operating conditions, this portion of the system is fed from the generating station at Thompson Falls, but it can receive energy from or supply energy to the main portion of the system through the Morel line. By the use of uni-directional relays in connection with the oil breakers at Drexel, Primrose and Gold Creek, and the use of proper time settings on these relays, provision can be made for cutting out any section of the line that may be in trouble.

In connection with Fig. 56, showing the 65 000 volt Missouri River system, the proper selection of the types of relays, and their proper time setting, greatly facilitates the automatic cutting out of any section of the line that is giving trouble. This 65 000 volt system ties in at Butte through suitable transformers to the 100 000 volt Montana Power system, and suitable relays at the Butte substation will separate the two systems in case of very serious trouble on one of them, so that the other will not be affected. The main generating stations on the Missouri River 65 000 volt system are at Canyon Ferry and Hauser Lake, but the entire 65 000 volt system can be fed through the Butte station from the 100 000 volt Montana Power system.

Fig. 55, which shows the 46 000 volt Madison River system, is considerably simpler than either of the others, but it is evident that the proper selection of relays will have a great deal to do with the satisfactory operation of the system.

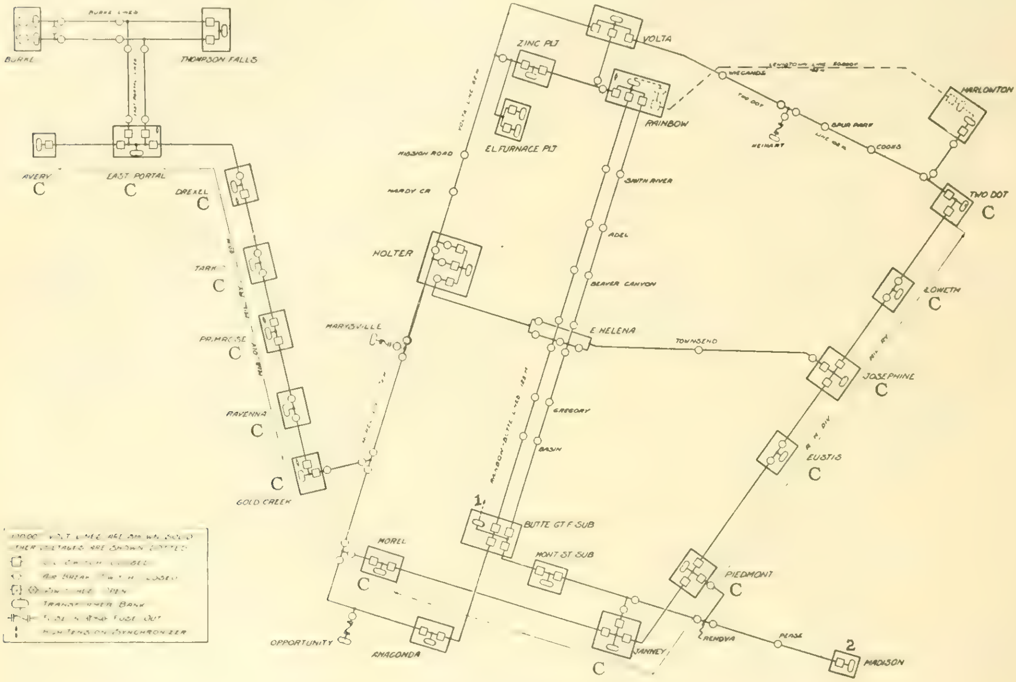


FIG. 58—THE 100 KV MONTANA POWER SYSTEM

1—The 65 000 volt system ties in here.
2—The 46 000 volt system ties in here.

Consideration of the various features brought out in the June number of the JOURNAL, will show where overload relays, reverse power relays, cross-connected relays, etc. can be employed to the best advantage. The actual relaying arrangement on the systems of the Montana Power Company, does not exactly correspond with the schemes outlined in the June number, although many of the features mentioned are utilized.

Electrical Characteristics of Transmission Circuits-XIII

Comparison of Various Methods (Concl.)

WM. NESBIT

MIDDLE CONDENSER OR NOMINAL T METHOD

THIS METHOD assumes that the total capacitance of the circuit may be concentrated at its middle point. In such a case the entire charging current would flow over half of the circuit. The resistance and the reactance on each side of the capacitance or condenser is equal respectively to half the total conductor resistance and conductor reactance.

From an inspection of the diagram of such a circuit, Fig. 56, it is evident that two calculations will be required. Starting with the known receiving-end conditions, the conditions at the middle of the circuit are first calculated by the simple impedance method. To these calculated results the current consumed by the condenser shunted across the middle of the circuit must be vectorially added. This will give the load condition at the middle of the circuit from which the sending-end conditions may be calculated.

Solution by Impedance Method—The diagram of connections and the corresponding graphical vector solution for problem X by the nominal T method is indicated by Fig. 56. The electrical conditions at the middle of the circuit may be determined as follows:—

$I_R \frac{R}{2} = 99.92 \times 52.5 = 5246$ *volts (resistance drop)*

$I_R \frac{X}{2} = 99.92 \times 124.5 = 12\,440$ *volts (reactance drop)*

$E_{mn} = \sqrt{}$ [illegible]
$= 70\,753 \angle 33^\circ\ 04'\ 36''$ *to current vector OD*
$= 70\,753 \angle 7^\circ\ 14'\ 05''$ *to vector of reference OR*

The current consumed by the condenser (zero leakage assumed) leads the voltage OM at the middle of the circuit by 90 degrees and is:—

$I_c = 0.001\,563 \times 70\,753 = 110.587$ *amperes*

The voltage consumed by the condenser current flowing back to the sending-end is:—

$I_c \frac{R}{2} = 110.587 \times 52.5 = 5806$ *volts (resistance drop)*
$= FC$

$I_c \frac{X}{2} = 110.587 \times 124.5 = 13\,768$ *volts (reactance drop)*
$= FM$

The voltage vector OC upon which the impedance triangle corresponding to the receiving-end load current $I_R = I_L$ flowing over the sending-end half of the circuit is constructed, may be found as follows:—

$OC = \sqrt{(70\,753 - 13\,768)^2 + 5806^2}$
$= 57\,280 \angle 5^\circ\ 49'\ 03''$ *volts to vector OM*
$= 57\,280 \angle 13^\circ\ 03'\ 08''$ *volts to vector of reference OR*

The voltage OC leads the receiving-end current OD by the angle 33° 04′ 36″ + 5° 49′ 03″ = 38° 53′ 39″ which angle corresponds to a power-factor of 77.831 percent. The voltage at the sending-end will therefore be:—

$E_{sn} = \sqrt{}$ [illegible]
$= 69\,467 \angle 44^\circ\ 10'\ 14''$ *volts to vector OD*
$= 69\,467 \angle 18^\circ\ 19'\ 43''$ *volts to vector of reference OR*

If desired, the receiving-end current and the condenser current may be combined and the corresponding impedance triangle for the sending-end half of the circuit constructed on the end of vector OM as indicated by the dotted lines.

The current at the sending-end may be determined as follows:—

$OB = 99.92 \cos 33^\circ\ 04'\ 36'' = 83.727$ *amperes.*
$BD = 99.92 \sin 33^\circ\ 04'\ 36'' = 54.532$ *amperes.*
$BN = 110.587 - 54.532 = 56.055$ *amperes.*
$I_s = ON = \sqrt{(83.727)^2 + (56.055)^2}$
$= 100.76 \angle 33^\circ\ 48'\ 06''$ *amperes to vector OB.*
$= 100.76 \angle 41^\circ\ 02'\ 11''$ *amperes to vector of reference OR.*

The current at the sending-end leads the voltage at the sending-end by the angle 41° 02′ 11″ — 18° 19′ 43″ = 22° 42′ 28″, which corresponds to a power-factor at the sending-end of 92.25 percent leading.

The power at the sending-end is:—

$Kv\text{-}a_{sn} = 100.76 \times 69\,467 = 7000$ *kv-a.*
$Kw_{sn} = 7000 \times 0.9225 = 6457$ *kw.*
$Loss = 6457 - 5300 = 1157$ *kw.*

Solution by Complex Quantities—From table Q (Aug. '20, p. 352) the auxiliary constants corresponding to the nominal T method of solution are found as follows:—

$a_1 = 1 - \frac{XB}{2} = 0.805\,406\,5$

$a_2 = \frac{RB}{2} = 0.082\,057\,5$

$b_1 = R - \frac{RXB}{2} = 84.5677$

$b_2 = X$ [illegible]

$c_1 = O$

$c_2 =$ [illegible]

The voltage at the sending-end is obtained as follows:—

[illegible] $j\,43\,554$
[illegible]
[illegible]

$E_{sn} = 65\,943 + j\,21\,845$
$= 69\,467 \angle 18^\circ\ 19'\ 43''$

The current at the sending-end may be calculated as follows:—

$I_R = I_R(\cos\theta_R - j\sin\theta_R) = 80.628 - j\,43.554$
[illegible] $= 76.0026 - j\,27.$ [illegible]
[illegible] $= 0 + j\,103.$ [illegible]

$I_s = 76.0026 + j\,66.15$ [illegible]
$= 100.76 \angle 41^\circ\ 02'\ 11''$ *amperes*

The above results check with those previously obtained by impedance calculations. This agreement indicates that the nominal T solution may, if desired, be made by complex quantities, assuming values for the auxiliary constants as indicated in Table Q.

Convergent Series Expression—Table Q indicates that the nominal T solution is equivalent to using the following values for the auxiliary constants in the convergent series form of solution:—

$$A' = \left(1 + \frac{ZY}{2}\right)$$
$$B' = Z\left(1 + \frac{ZY}{4}\right)$$
$$C' = Y$$

Comparing the above expressions for the auxiliary constants with the complete expression yielding rigorous values the following difference may be noted.

For auxiliary constant A' the first two terms in the complete series for the hyperbolic cosine are used and all terms beyond omitted. For auxiliary constant B' the first two terms of the complete series are also used except that the coefficient of the second term is given as ¼, whereas in the complete series it is 1/6. Auxiliary constant C' is equivalent to the first term only of the complete expression.

We will now show that the above expressions yield the same values for the auxiliary constants as given in Table Q. From Chart XI the following values corresponding to problem X are taken:—

$ZY =$ [illegible]
$= $ [illegible] $+ j\,0.164\,115$
Then for $A' = 1 +$ [illegible]
$=$ [illegible] $+ j\,0.0820\,575$
$A' =$ [illegible] $+ j\,0.0820\,575$
$B' = 1 +$ [illegible]
$=$ [illegible] $+ j\,0.04\,102\,875$
$= Z\,(0.00\,270\,325 + j\,0.04\,102\,875)$
$B' =$ [illegible]
$C' = 0 + j\,0.001\,563$

Thus the values for the auxiliary constants as determined by the above incomplete convergent series expressions check exactly with those as determined above from the equations in Table Q.

THREE CONDENSER METHOD

This method (proposed by Dr. Chas. P. Steinmetz) assumes that the admittance of the circuit may be lumped or concentrated across the circuit at three points, one-sixth being localized at each end and two-thirds at the middle of the circuit. This is equivalent to assuming that the electrical quantities are distributed along the circuit in a manner represented by the arc of a parabola. It is evident that this method more nearly approaches the actual distribution of the impedance and the admittance of the circuit than any of the three previously described localized admittance methods, and therefore yields more accurate results.

From an inspection of the diagram of such a circuit, Fig. 57, it will be evident that it is necessary to calculate the performance of the two halves of the circuit in order to arrive at the sending-end voltage and an additional calculation will be required to determine the sending-end current, power and power-factor.

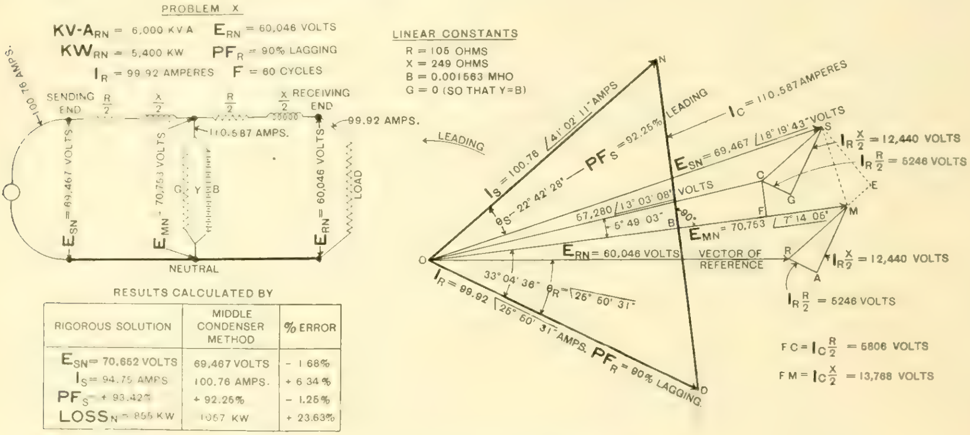
Solution by Impedance Method—The diagram of connections and corresponding graphical vector solution for problem X by the three condenser method is indicated by Fig. 57. The charging current consumed by the condenser (zero leakage assumed) at the receiving-end leads the receiving-end voltage by 90 degrees and is:—

$$I_{cr} = \frac{0.001\,563}{6} \times 60\,046 = 15.642 \textit{ amperes}$$

The current per conductor for the receiving-end half of the circuit is:—

$$I_r = (99.92 \times 0.9) - j\,(99.92 \times 0.4359 - 15.642)$$
$$= 94.16 \diagdown 17^\circ\ 14'\ 38'' \textit{ amperes}$$
$$PF_r = Cos \diagdown 17^\circ\ 14'\ 38'' = 95.505 \textit{ lagging}$$

The voltage consumed by the resistance and the reactance per conductor between the receiving-end and the middle of the circuit is:—



RESULTS CALCULATED BY

RIGOROUS SOLUTION	MIDDLE CONDENSER METHOD	% ERROR
E$_{SN}$ = 70,652 VOLTS	69,467 VOLTS	− 1.68%
I$_S$ = 94.75 AMPS	100.76 AMPS.	+ 6.34%
PF$_S$ = 93.42%	+ 92.25%	− 1.25%
LOSS$_N$ = 855 KW	1057 KW	+ 23.63%

FIG. 56—NOMINAL T OR MIDDLE CONDENSER METHOD

$$I_r \frac{R}{2} = 94.16 \times 52.5 = 4943.4 \textit{ Volts (resistance drop)}$$

$$I_r \frac{X}{2} = 94.16 \times 124.5 = 11\,723 \textit{ Volts (reactance drop)}$$

The voltage at the middle of the circuit is from (30):—

$E_{mn} = \sqrt{}$ [illegible]

$= 68\,933 \;/25° \; 21' \; 33''$ *volts to current vector OP*

$= 68\,933 \;/8° \; 06' \; 55''$ *volts to vector of reference OR*

The charging current consumed by the condenser (zero leakage assumed) at the middle of the circuit leads the voltage at the middle of the circuit by 90 degrees and is:—

$$I_{cm} = \frac{0.001563}{1.5} \times 68\,933 = 71\,828 \textit{ amperes}$$

The current per conductor for the sending-end half of the circuit may be determined as follows:—

$OT = \text{Cos } 25° \; 21' \; 33'' \times 94.16 = 85.0867$ *amperes*

$TP = \text{Sin } 25° \; 21' \; 33'' \times 94.16 = 40.3278$ *amperes*

$TV = 71.828 - 40.3278 = 31.5002$ *amperes.*

$I_m = \sqrt{85.0867^2 + 31.5002^2}$

$= 90.73 \;/20° \; 18' \; 55''$ *amperes to voltage vector OM at middle.*

$= 90.73 \;/28° \; 25' \; 50''$ *to vector of reference OR*

The voltage consumed by the resistance and the reactance per conductor between the middle and sending-end of the circuit is:—

$$I_m \frac{R}{2} = 90.73 \times 52.5 = 4763.3 \textit{ volts (resistance drop)}$$

$$I_m \frac{X}{2} = 90.73 \times 124.5 = 11\,296 \textit{ volts (reactance drop)}$$

The voltage at the sending-end from (40) is:—

$E_{sn} = \sqrt{}$ [illegible]

$= 70\,548 \;\backslash 10° \; 19' \; 07''$ *volts to current vector OV*

$= 70\,548 \;/18° \; 06' \; 43''$ *volts to vector of reference OR*

The charging current consumed by the condenser (zero leakage assumed) at the sending-end of the circuit leads the voltage at the sending-end by 90 degrees and is:—

$$I_{cs} = \frac{0.001563}{6} \times 70\,548 = 18.3777 \textit{ amperes}$$

The current at the sending-end of the circuit may be determined as follows:—

$OS = \text{Cos } 10° \; 19' \; 07'' \times 90.73 = 89.2624$

$VS = \text{Sin } 10° \; 19' \; 07'' \times 90.73 = 16.2516$

$NS = 16.2516 + 18.3777 = 34.6293$ *amperes.*

$I_s = \sqrt{89.2624^2 + 34.6293^2}$

$= 95.744 \;/21° \; 12' \; 13''$ *to voltage vector OS.*

$= 95.744 \;/39° \; 18' \; 56''$ *to vector of reference OR.*

$Kv\text{-}a_s = 95.744 \times 70.548 = 6755$ *kv-a*

$PF_s = \text{Cos } (39° \; 18' \; 56'' - 18° \; 06' \; 43'')$

$= \text{Cos } 21° \; 12' \; 13'' = 93.23$ *percent leading*

$Kw_s = 6755 \times 0.9323 = 6298$ *kw*

$Loss_N = 6298 - 5400 = 898$ *kw*

$$Eff. = \frac{5400 \times 100}{6298} = 85.75 \textit{ percent}$$

Solution by Complex Quantities—From Table Q the auxiliary constants corresponding to the three condenser method of solution are found to be:—

$$a_1 = 1 - \frac{XB}{2} + \frac{B^2}{36}(X^2 - R^2) = 0.808806$$

$$a_2 = \frac{RB}{2} - \frac{RXB^2}{18} = 0.0785091$$

$$b_1 = R - \frac{RXB}{3} = 91.3785$$

$$b_2 = X - \frac{B}{6}(X^2 - R^2) = 235.7208$$

$$c_1 = -\frac{5RB^2}{36} + \frac{RXB^3}{108} = -0.0000347$$

$$c_2 = B - \frac{5XB^2}{36} + \frac{B^3}{216}(X^2 - R^2) = +0.0014704$$

These values for the auxiliary constants are in close agreement with the rigorous values.

$I_r ((\text{Cos } \theta_r$ [illegible] $) = 18\,491 + j\,17\,218$

$E_r (a_1 + j\,a_2) = 48\,560 + j\,4\,714$

$E_s = 67\,053 + j\,21\,932$

$= 70\,548 \;/18° \; 06' \; 43''$ *volts*

The current at the sending-end is:—

$I_r ((\text{Cos } \theta_r - j \text{ Sin } \theta_r) (a_1 + j\,a_2)$

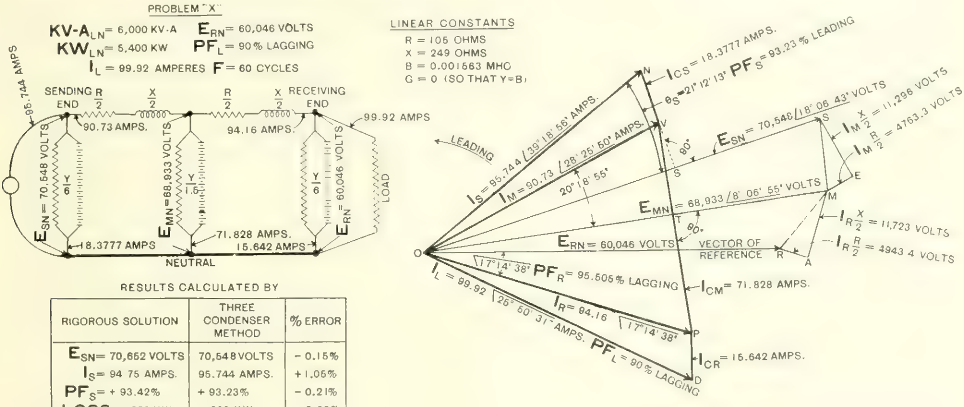
$= 76.159 - j\,28.170$

$E_r (c_1 + j\,c_2) = -2.084 + j\,88.832$

$I_s = 74.075 + j\,60.662$

$= 95.744 \;/39° \; 18' \; 56''$ *amperes*

By comparing these results with those obtained



RESULTS CALCULATED BY

RIGOROUS SOLUTION	THREE CONDENSER METHOD	% ERROR
E$_{SN}$= 70,652 VOLTS	70,548 VOLTS	- 0.15%
I$_S$= 94 75 AMPS.	95.744 AMPS.	+ 1.05%
PF$_S$= + 93.42%	+ 93.23%	- 0.21%
LOSS$_N$= 855 KW	898 KW	+ 5.03%

FIG. 57—DR. CHAS. P. STEINMETZ'S THREE CONDENSER METHOD

CHART XXII—COMPARISON OF RESULTS BY VARIOUS METHODS

PROBLEM NO.	LENGTH OF CIRCUIT—MILES	CONDUCTORS	SPACING IN FEET—DELTA	LINEAR CONSTANTS				LOAD AT RECEIVING-END					% ERROR IN RECEIVING-END VOLTAGE AS DETERMINED BY								
				R	X	B x 10⁻⁶	G	KV-A ★	E_R	E_{RN}	P F %	I_R	RIGOROUS SOLUTION THESE VALUES ARE EXACT E_{SN}	SEMI-GRAPHICAL METHOD % ERROR	COMPLETE GRAPHICAL METHOD % ERROR	H. B. DWIGHT'S "K" FORMULAS % ERROR	DR. CHAS. P. STEINMETZ'S THREE CONDENSER METHOD % ERROR	NOMINAL "T" OR MIDDLE CONDENSER METHOD % ERROR	NOMINAL "π" OR SPLIT CONDENSER METHOD % ERROR	SINGLE END CONDENSER METHOD % ERROR	IMPEDANCE METHOD % ERROR
25 CYCLES																					
1	20	#0000	3	5.54	5.36	57.2	0	1,300	10,000	5,774	80	75	6,347	0	+.05	0				-.01	0
2	"	COPPER	"	"	"	"	0	"	"	"	100	"	6,202	0	+.03	0				-.01	0
3	20	#0000	3	5.54	5.36	57.2	0	5,000	20,000	11,550	80	144.4	12,653	-.04	+.06	-.01				-.02	+.02
4	"	COPPER	"	"	"	"	0	"	"	"	100	"	12,372	-.05	+.02	-.01				-.02	+.02
5	30	#0000	4.	8.31	8.5	81	0	3.500	20,000	11,550	80	101	12,733	+.02	+.06	-.02				-.03	+.04
6	"	COPPER	"	"	"	"	0	"	"	"	100	"	12,415	+.08	+.04	-.02				-.03	+.04
7	30	#0000	4	8.31	8.5	81	0	8,000	30,000	17,320	80	154	19,125	+.05	0	-.01				-.03	+.03
8	"	COPPER	"	"	"	"	0	"	"	"	100	"	18,640	+.08	+.05	+.01				-.02	+.03
9	50	#0000	4	13.85	[illegible]	135	0	5,000	30,000	17,320	80	96.2	19,184	0	-.07	+.03				-.08	+0.1
10	"	COPPER	"	"	"	"	0	"	"	"	100	"	18,685	-.05	-.03	+.02				-.05	+0.1
11	50	#0000	6	13.85	15.1	125	0	20,000	60,000	34,640	80	192.5	38,490	-.03	-.04	+.01			0	-.08	+0.1
12	"	COPPER	"	"	"	"	0	"	"	"	100	"	37,387	-.02	-.03	+.01			0	-.07	+0.1
13	100	#0000	9	27.7	32.2	233	0	22,000	88,000	50,810	80	144.4	56,619	-.07	-.03	0		-.01	+.01	-.31	+0.3
14	"	COPPER	"	"	"	"	0	"	"	"	100	"	54,820	-.02	-.04	0		-.01	+.01	-.30	+0.3
15	100	#0000	11	27.7	33.2	226	0	40,000	120,000	69,290	80	192.5	77,147	-.02	-.06	0		-.01	+.02	-.30	+0.4
16	"	COPPER	"	"	"	"	0	"	"	"	100	"	74,642	-.02	-.03	0		-.01	+.02	-.31	+0.4
17	200	300,000 C.M.	11	39.2	64.8	464	0	25,000	120,000	69,290	80	120.3	76,754	+.06	-.01	0		-.04	+.06	1.24	+1.4
18	"	COPPER	"	"	"	"	0	"	"	"	100	"	73,401	+.05	-.06	0		-.04	+.06	-1.24	+1.4
19	200	300,000 C.M.	17	39.2	69.2	434	0	40,000	140,000	80,830	80	165	91,761	-.02	+.05	-.08		-.05	+.06	-1.19	+1.4
20	"	COPPER	"	"	"	"	0	"	"	"	100	"	86,863	-.02	.01	+.01		-.04	+.05	-1.19	+1.4
21	300	636,000 C.M.	11	44.1	91.2	747	0	20,000	120,000	69,290	80	96.2	75,682	0	+.02	+.05		-.09	+.15	-2.83	+3.2
22	"	ALUMINUM	"	"	"	"	0	"	"	"	100	"	71,762	+.08	-.02	+.02		-.08	+.13	-2.88	+3.2
23	300	636,000 C.M.	21	44.1	101	672	0	60,000	200,000	115,500	80	173.2	128,450	-.04	+.04	+.03		-.11	+.17	-2.74	+3.4
24	"	ALUMINUM	"	"	"	"	0	"	"	"	100	"	120,574	0	-.06	+.01		-.11	+.15	-2.82	+3.3
25	400	636,000 C.M.	17	58.8	130	928	0	20,000	140,000	80,830	80	82.5	86,404	-.05	—	+.11	0	-.19	+.26	-5.08	+5.7
26	"	ALUMINUM	"	"	"	"	0	"	"	"	100	"	81,647	-.06	—	+.05	0	-.18	+.23	-5.30	+5.7
27	400	636,000 C.M.	21	58.8	134	896	0	50,000	200,000	115,500	80	144.4	127,267	-.05	—	+.09	0	-.22	+.32	-4.80	+5.6
28	"	ALUMINUM	"	"	"	"	0	"	"	"	100	"	118,833	-.03	—	0	0	-.21	+.29	-4.89	+5.6
29	500	636,000 C.M.	17	73.5	163	1160	0	15,000	140,000	80,830	80	61.86	83,045	-.06	—	+.06	-0.04	-.27	+.36	-8.22	+9.2
30	"	ALUMINUM	"	"	"	"	0	"	"	"	100	"	78,658	+.05	—	+.01	-0.04	-.23	+.31	-8.32	+9.3
31	500	636,000 C.M.	21	73.5	168	1120	0	40,000	200,000	115,500	80	115.5	123,401	+.08	—	+.02	-0.04	-.40	+.50	-7.65	+9.0
32	"	ALUMINUM	"	"	"	"	0	"	"	"	100	"	115,162	+.08	—	-.02	-0.04	-.37	+.44	-5.99	+9.0
60 CYCLES																					
33	20	#0000	3	5.54	12.88	137	0	1,300	10,000	5,774	80	75	6,702	0	-.15	0				-.07	+.07
34	"	COPPER	"	"	"	"	0	"	"	"	100	"	6,259	+.06	+.02	+.02				-.06	+0.1
35	20	#0000	3	5.54	12.88	137	0	5,000	20,000	11,550	80	144.4	13,333	+.02	-0	0				-.07	+0.1
36	"	COPPER	"	"	"	"	0	"	"	"	100	"	12,480	+.02	+.04	0				-.07	+0.1
37	30	#0000	4	8.31	20.4	195	0	3,500	20,000	11,550	80	101	13,482	+.07	+.06	0				-.15	+0.2
38	"	COPPER	"	"	"	"	0	"	"	"	100	"	12,537	+.05	+.06	0				-.16	+0.2
39	30	#0000	4	8.31	20.4	195	0	8,000	30,000	17,320	80	154	20,268	+.03	+.06	+.01		0	0	-.15	+0.2
40	"	COPPER	"	"	"	"	0	"	"	"	100	"	18,830	-.03	+.05	+.02		0	0	-.16	+0.2
41	50	#0000	4	13.85	34	324	0	5,000	30,000	17,320	80	96.2	20,331	0	+.04	+.03		-.02	+.04	-.42	+0.5
42	"	COPPER	"	"	"	"	0	"	"	"	100	"	18,845	+.08	-.03	-.02		-.02	+.03	-.44	+0.5
43	50	#0000	6	13.85	36.4	300	0	20,000	60,000	34,640	80	192.5	40,976	+.03	-.01	+.02		-.02	+.03	-.41	+0.5
44	"	COPPER	"	"	"	"	0	"	"	"	100	"	37,773	+.04	-.0	+.03		-.02	+.04	-.42	+0.5
45	100	#0000	9	27.7	77.4	562	0	22,000	88.000	50,810	80	144.4	59,925	+.03	-.09	+.08	0	-.08	+.13	-1.61	+1.91
46	"	COPPER	"	"	"	"	0	"	"	"	100	"	54,869	0	-.13	+.05	0	-.07	+.13	-1.69	+1.96
47	100	#0000	[illegible]	27.7	79.7	542	0	40,000	120,000	69,290	80	192.5	81,710	-.08	-.06	-.02	0	-.08	+.14	-1.60	+1.84
48	"	COPPER	"	"	"	"	0	"	"	"	100	"	74,735	-.05	.1	+.01	0	-.07	+.12	-1.68	+1.92
49	200	300,000 C.M.	[illegible]	39.2	156	[illegible]	0	25,000	120,000	69,290	80	120.3	79,000	+.03	+.14	+.18	-0.04	-.46	+.61	-6.53	+7.8
50	"	COPPER	"	"	"	"	0	"	"	"	100	"	70,599	+.08	+.07	+.14	-0.04	-.39	+.47	-6.99	+8.1
51	200	[illegible] C.M.	[illegible]	39.2	166	1044	0	40,000	140,000	80,830	80	165	96,727	-.07	+.14	+.22	-0.04	-.51	+.73	-5.96	+7.5
52	"	COPPER	"	"	"	"	0	"	"	"	100	"	84,862	+.07	+.02	+.25	-0.04	-.45	+.62	-6.37	+7.8
53	300	636,000 C.M.	[illegible]	44.1	[illegible]	[illegible]	0	20,000	120,000	69,290	80	96.2	72,747	-.04	+.05	+.46	-0.21	-1.51	+1.34	-15.68	+19
54	"	ALUMINUM	"	"	"	"	0	"	"	"	100	"	63,810	-.02	+.2	-.25	-0.21	-1.34	+1.01	-16.43	+20
55	300	636,000 C.M.	21	44.1	243	1614	0	60,000	200,000	115,500	80	173.2	126,541	-.05	+25	+.46	-0.21	-1.60	+1.60	-14.50	+18
56	"	ALUMINUM	"	"	"	"	0	"	"	"	100	"	109,189	-.07	+.15	+.5	-0.21	-1.44	+1.29	-15.12	+19
57	400	636,000 C.M.	17	58.8	314	[illegible]	0	20,000	140,000	80,830	80	82.5	74,182	+.01	—	.08	-0.71	-3.92	+2.15	-29.34	+37
58	"	ALUMINUM	"	"	"	"	0	"	"	"	100	"	64,377	+.03	—	.0	-0.71	-3.65	+1.74	-27.16	+39
59	400	636,000 C.M.	21	58.8	322	[illegible]		50,000	200,000	115,500	80	144.4	113,606	-.08	—	.49	-0.75	-4.11	+2.09	-25.82	+35
60	"	ALUMINUM	"	"	"	"	0	"	"	"	100	"	96,987	+.01	—	+1.04	-0.81	-3.92	+2.84	-22.38	+36
61	500	636,000 C.M.	17	73.5	390	2784	0	15,000	140,000	80,830	80	61.86	59,046	+.06	—	-1.47	-1.97	-9.18	+2.28	-40.82	+70
62	"	ALUMINUM	"	"	"	"	0	"	"	"	100	"	51,327	+.06	—	+.25	-1.89	-8.64	+2.54	-20.62	+73
63	500	636,000 C.M.	21	73.5	402	2690	0	40,000	200,000	115,500	80	115.5	93,725	+.06	—	-.28	-1.84	-9.32	+4.44	-35.54	+64
64	"	ALUMINUM	"	"	"	"	0	"	"	"	100	"	80,106	+.06	—	+3.8	-1.72	-8.84	+5.43	-13.53	+65

*It would be commercially impractical to transmit such small amounts of power some of the extreme distances indicated by the tabulation. The problems are stated simply for the purpose of illustrating in an approximate manner the effect distance of transmission has upon the voltage drop as calculated by various methods.

by the impedance method of procedure, it will be seen that they are in exact agreement.

Convergent Series Expression—Dr. F. E. Pernot in "Electrical Phenomena in Parallel Conductors," Vol. I, shows that the above described three condenser solution is equivalent to using the following values for the auxiliary constants in the convergent series form of solution:—

$$A' = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{36}\right)$$

$$B' = Z\left(1 + \frac{ZY}{6}\right)$$

$$C' = Y\left(1 + \frac{5\,ZY}{36} + \frac{Z^2Y^2}{216}\right)$$

Comparing the above expressions for the auxiliary constants with the complete expressions yielding rigorous values, the following differences may be noted. For constant A' the first two terms are the same as in the complete series, but the third term is less than in the complete series, and all terms beyond the third are omitted. For constant B' the first two terms are the same as in the complete series, but all terms beyond the second are omitted. For constant C' both the ZY and the Z^2 Y^2 terms are smaller than in the complete series and all terms beyond the third are omitted.

The above expressions yield the same values for the auxiliary constants as given in Table Q. Thus from chart XI, the following values corresponding to problem X are taken:—

$$\begin{aligned} ZY &= -\,0.389187 + j\,0.164115 \\ Z^2Y^2 &= +\,0.124532 - j\,0.127742 \end{aligned}$$

Therefore

$$\begin{aligned} A' = &\ \ 1.000000 \\ &-0.194593 + j\,0.0820575 \\ &\ \ 0.003459 - j\,0.0035484 \\ \hline A' = &\ \ 0.808866 + j\,0.0785091 \\ B' = &\ \ 1.000000 \\ &-0.0648645 + j\,0.0273525 \\ \hline &\ Z\,(0.9351355 + j\,0.0273525) \\ B' = &\ \ 91.3785 \quad + j\,235.7208 \\ C' = &\ \ 1.000000 \\ &-0.0540538 + j\,0.0227938 \\ &+0.0005765 - j\,0.0005914 \\ \hline &\ Y\,(0.9465227 + j\,0.0222024) \\ C' = &-0.0000347 + j\,0.0014704 \end{aligned}$$

It will be seen that the above convergent series expression for the auxiliary constants check exactly with those as determined by the equations in Table Q.

COMPARATIVE ACCURACY OF VARIOUS METHODS

In order to determine the inherent error in various methods of solution, when applied to circuits of increasing length; also for frequencies of both 25 and 60 cycles, 64 problems were solved. These problems embrace thirty-two 25 cycle circuits, varying in length from 20 to 500 miles and in voltage from 10 000 to 200 000 volts. Fixed receiving-end load conditions were assumed for unity, and also for 80 percent power-factor lagging. These same problems were also solved for a frequency of 60 cycles.

These 64 problems with corresponding linear constants and assumed load conditions are stated on Chart XXII. This is followed by columns in which have been tabulated the error in voltage at the sending-end of these circuits as determined by nine different methods. The errors are expressed in percent of receiving-end voltage. Obviously the inherent error corresponding to various methods will vary widely for conductors of various resistances and to some extent for different receiving-end loads. The tabulated values should therefore be looked upon as comparative rather than absolute for all conditions.

Rigorous Solution—The column headed "Rigorous Solution" contains values for the sending-end voltage which are believed to be exact. These values were obtained by calculating values for the auxiliary constants by means of convergent series and then calculating the performance mathematically. The calculations were carried out to include the sixth place and terms in convergent series were used out to the point where they did not influence the results.

The first values calculated were checked by a second set of values calculated independently at another time and where differences were found the correct values were determined and substituted. This corrected list of values was again checked by a third independent calculation. It is therefore believed that the values contained in this column are exact, representing 100 percent.

Semi-Graphical Solution—The next column contains the error in the results as derived by the combination of an exact mathematical solution for the auxiliary constants and a graphical solution from there on. This combination gave results in which the maximum error does not exceed eight one hundredths of one percent of receiving-end voltage for either frequency. In other words, since the values for the auxiliary constants used in this method were exact, the maximum error of eight one hundredths of one percent occurs in the construction and reading of the graphical constructions.

Complete Graphical Solution—This solution employs Wilkinson's charts for obtaining graphically the auxiliary constants, the remainder of the solution being also made graphically as previously described. It will be seen that the maximum error as obtained by this complete graphical solution is seven hundredths of one percent for the 25 cycle and twenty-five hundredths of one percent for the 60 cycle circuits. These errors represent the combined result of various errors. First there is a slight fundamental error in the basis upon which the Wilkinson Charts are constructed when used for circuits employing conductors of various sizes and spacings, the introduction of this error making possible the simplification attained. Then there is the inherent limitation of precision obtainable in the construction and reading of the charts and vector diagrams.

These results show that the inherent accuracy of this simplified, all graphical solution is sufficiently accurate for all practical power circuits up to 300 miles long.

Dwight's "K" Formulas—The high degree of accuracy resulting by the use of H. B. Dwight's "K" formulas should be noted. This error is a maximum of eleven hundredths of one percent for these 32 twenty-five cycle problems. The statement is therefore justified that these "K" formulas are sufficiently accurate for all 25 cycle power circuits.

For the 60 cycle problems the maximum error by the "K" formulas for problems up to and including 200 miles is one-fourth of one percent of receiving-end voltage. For 300 mile circuits this error is one-half of one percent and increases rapidly as the circuit exceeds 300 miles in length. The accuracy of the "K" formulas for 60 cycle circuits is therefore well within that of the assumed values of the linear constants for circuits up to approximately 300 miles in length.

The "K" formulas are based upon the hyperbolic formula expressed in the form of convergent series. In the development of these formulas, use was made of the fact that the capacitance multiplied by the reactance of non-magnetic transmission conductors is a constant quantity to a fairly close approximation. This assumption has enabled the "K" formulas to be expressed in comparatively simple algebraic form without the use of complex numbers. To those not familiar or not in position to make themselves familiar with the operation of complex numbers, such as is used in the convergent series or hyperbolic treatments, the availability of the Dwight "K" formulas will be apparent.*

Localized Capacitance Methods—The next four columns contain values indicating the error in results as determined by the four different localized capacitance methods previously described in detail. It is interesting to note the high degree of accuracy inherent in Dr. Steinmetz's three condenser method. It is also interesting to note that three of these methods over compensate (that is, give receiving-end voltages too low) and one (the split condenser method) gives under compensation.

Impedance Method—The values of the sending-end voltage as obtained by the impedance method (which takes no account of capacitance) are always too high when applied to circuits containing capacitance. The results by this method are included here simply to serve as an indication of how great is the error for this method when applied to circuits of various lengths and frequencies of 25 and 60 cycles. Some engineers prefer to use this method for circuits of fair length and allow for the error. These tabulations will give an approximation of the necessary allowance to be made.

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*These have been included with much other valuable material in "Transmission Line Formulas" by H. B. Dwight, published by D. Van Nostrand Co. of New York City.

Direct-Current Motors for Crane and Hoist Work

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Motor Engineering Dept.,
Westinghouse Electric & Mfg. Company

THE APPLICATION of direct-current motors to cranes and hoists has become an important branch of electrical engineering, demanding a considerable proportion of the direct-current motors manufactured. The outstanding characteristic of this service is the fluctuating character of the load. For a short time while lifting, the hoist motor is heavily loaded. Following this is a period of rest; then comes a period of light load while lowering. To complete the cycle, the hook must be raised, the crane brought back to position and the hook lowered ready for another load. If the load on the hook is moderate, the weight may not be sufficient to overcome the friction of the gearing, and a small load may be imposed upon the motor while lowering. However, if the load is heavy, the weight may more than counter-balance the friction and it will be necessary to use some method of braking in order to limit the speed. When dynamic braking is used, the motor delivers electrical energy and is heated in the same manner as in normal operation. The speed is usually high while lowering and the time somewhat shorter than when hoisting.

Motors for bridge or trolley work or for similar purposes also are loaded intermittently, but the load during the working part of the cycle is more constant than with the hoist motor and the peak values are relatively not as high. The dead weight of the crane is a large part of the total weight, so the load on the motor does not differ greatly with the hook loaded or empty. The maximum values occur on starting, when the load has to be accelerated and the static friction overcome.

As varying speed motors are satisfactory for such service, the advantages of series motors can be secured. The ruggedness and simplicity of series motors are well known. For hoisting work, they have the further advantage that they are smaller than a constant speed motor built for the same average load. This is a result of their speed being high under light load and low under heavy load.

On account of the location, the maintenance of crane motors is usually more difficult than that of general service motors. The maintenance of the commutator and brushes is usually a considerable item in the expense of repairs. The way to reduce this expense is to design the motor so that good commutation will be obtained under all conditions.

An important requirement of motors for this class of service is that they be rugged mechanically. The motors do not have a solid foundation and are subject to considerable vibration from the connected gearing. Also there are sudden shocks from plugging, peak loads and the application of brakes.

Enclosed motors are commonly used in crane and hoist work. There are locations where the dust is excessive and the utmost reliability is required. Enclosed motors are of course desirable under such conditions. In some locations the motor may be so exposed to dampness that it is preferably made enclosed. However, in a large majority of applications in machine shop, foundries and similar locations, motors that are merely drip-proof should be satisfactory. In the case of cranes which operate out doors, sufficient protection is often provided to make drip-proof motors satisfactory.

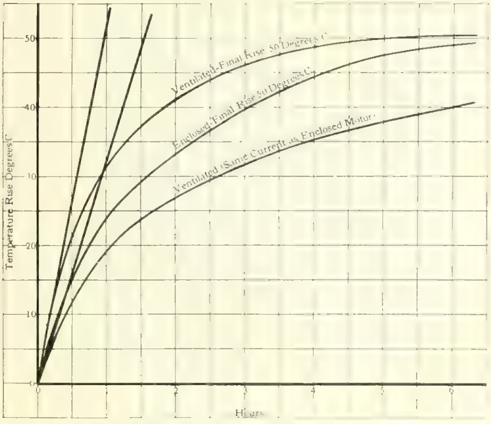


FIG. I—COMPARISON OF TEMPERATURE RISE OF ENCLOSED AND VENTILATED MOTORS

It is not necessary to enclose a motor totally to make it drip-proof; hence, a certain amount of ventilation can be arranged for. The ventilated motor has some advantage in weight over the totally enclosed motor where it is in use for hours at a time. This accounts for the use of ventilated motors in modern railway work. The advantages of ventilated motors can be realized in most crane applications also, as their greater compactness is an important factor. A comparison of enclosed and ventilated motors with regard to heating and efficiency is given in the following paragraphs.

HEATING OF VENTILATED AND ENCLOSED MOTORS

The motor temperature rise is determined by several factors:—the initial thermal conditions, the heat generated in the machine, the thermal capacity of the material and the ability to dissipate heat. The heat generated is equal to the losses in the machine and is subject to variation with the load. The heat absorption is a function of the temperature rise, the weight and the kind of material, of which the copper and the iron are the most important. The heat dissipation depends mainly upon the amount and character of the surface exposed, the volume of air circulated through the machine or around it, and the temperature rise above the air.

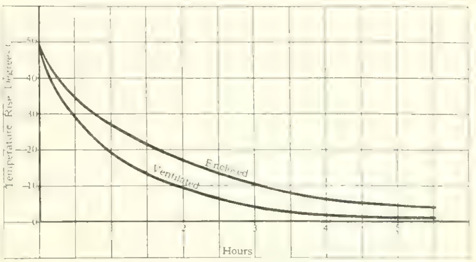


FIG. 2—COOLING CURVES AT SPEEDS CORRESPONDING TO CONTINUOUS RATING

In the case of a motor operating for a considerable period at a constant load, heat storage is not an important factor. When the load is continually fluctuating or the operation intermittent, much depends upon the ability of the material to absorb the surplus heat at overloads, when the losses are greater than can be carried away, and to dissipate them at light loads or during periods of rest. This storage capacity of the material retards the rise in temperature and makes it possible to carry heavy loads of short duration without excessive temperatures. It is very important, however, that the heavy loads be followed by periods of light load or rest, so that the surplus heat be dissipated and the temperature reduced to the initial value before the start of another overload. If this condition is not obtained in each cycle, the result will be a gradual accumulation of heat in the machine and destructive temperatures.

The advantage of the ventilated motor is its ability to get rid of more heat than an enclosed motor of the same size. Referring to Fig. 1, suppose a given motor is operated enclosed at a certain load. Its ability to dissipate heat will depend upon radiation and convection from the outer surface of the motor. Until the external surface becomes warm the heat is practically

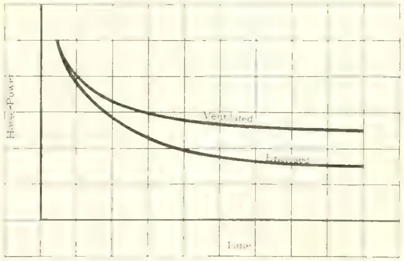


FIG. 3—TIME VARIOUS LOADS CAN BE CARRIED FOR A CERTAIN TEMPERATURE RISE

The two machines have the same short time rating.

all stored in the machine and the temperature increases almost in proportion to the time. If, however, sufficient air is drawn through the machine, the ultimate temperature for the same load will be considerably lower and reached more quickly.

Suppose a ventilated motor is loaded so as to attain the same final temperature as an enclosed motor. At first, owing to the low temperature, but little heat is carried away, and most of it is stored. The temperature, therefore, rises at first in proportion to the time, but rises faster than in the enclosed motor on account of greater losses. When the load is thrown off, the temperature of the ventilated motor will fall much faster than that of the enclosed motor if the machine continues to rotate, as indicated in Fig. 2. If the motor is stopped when its load is removed, which is the usual condition, it will cool in about the same length of time whether open or enclosed, since the ventilating feature is not then operative. Thus the advantage of the ventilated motor comes from its ability to dissipate more heat when running, and therefore to carry higher average loads. The two curves, Fig. 3, indicate the time during which various loads can be carried for a certain temperature rise, the two machines having the same short time rating. The ventilation does not influence the capacity for short time ratings, but increases the capacity for long periods.

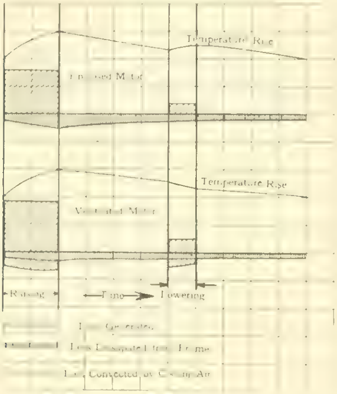


FIG. 4—VARIATION IN LOSS AND TEMPERATURE RISE
For ventilated and enclosed motors during a simple hoist cycle.

The variations in loss and temperature rise for a ventilated and an enclosed motor during a simple hoist cycle are shown in Fig. 4. The positive ordinates indicate the rate at which heat is generated, and the negative ordinates indicate the rate at which it is dissipated. During the period of heavy load, the losses are high and the temperature rises rapidly, the ventilated motor dissipating more loss than the enclosed motor. During the rest period following, both the open and the enclosed motor cool off at practically the same rate. During the lowering period a certain amount of heat is generated and some heat is radiated from both motors, but in addition the ventilated motor dissipates a considerable quantity of heat by virtue of the air drawn through it. This is very effective at this time because of the relatively high speed. The temperature of the enclosed motor thus reaches a peak at the close of the period of heavy load and falls during the rest of the cycle, except for a probable rise during the period of light load. The peak temperature of the ventilated motor occurs at the same time, but its temperature likely will fall considerably during the period of light load. In the case of bridge and trolley motors, which do not have corresponding periods of light load, the total heat generated during the period of load must be dissipated during the load and rest periods; otherwise the heat will accumulate. The ventilated motor has an advantage here also, since it can dissipate more heat during the period of running than the enclosed motor, though the gain is less marked.

In the preceding, it was assumed that the cycle had been repeated for a sufficient time to bring the average temperature to a constant value. If instead, the machine starts cold, the temperature of the ventilated motor will rise more rapidly at the start than that of the enclosed motor, if the two are designed for the same ultimate temperature, because it contains less active material to absorb the heat.

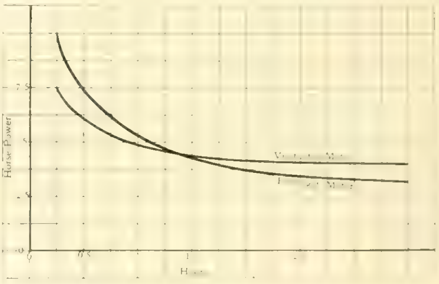


FIG. 5—COMPARISON OF HEATING CHARACTERISTICS OF TOTALLY ENCLOSED AND VENTILATED MOTORS

RATING

Whether the crane motor is built ventilated or enclosed, it should have about the same speed-torque curve for a given application. It should also have to stand the same peak loads in either case; hence the mechanical parts, such as the shaft, bearings, brackets and to a certain extent the frame would be about the same for either condition. The commutator and the brush rigging also would be similar in the two cases. The principal difference would be found in the active material, and would depend mostly upon the time rating required.

The amount of load, the durations of the load periods, and of the rest periods and the time during which the cycle is repeated, will determine the time rating required. If the crane or hoist is used for only a few minutes at a time, with long rest periods intervening, it will do little good to ventilate the motor; that is, about the same amount of active material will be required whether the motor is enclosed or open. An example of this kind is a crane intended mainly for use in emergency, such as a power house crane.

Where the crane is used at frequent intervals for hours at a stretch, the continuous capacity of the motor is the important factor. Such service as this is required of cranes for general machine shop and foundry work. In such a case, less active material is required in the ventilated motor, owing to its ability to dissipate more loss.

It is obviously impracticable to test a hoist motor with the kind of load which it will get in actual service. Some compromise test and rating must be adopted. The usual practice with enclosed motors has been to rate crane and hoist motors on the half hour basis. For ordinary work the motor horse-power required when the crane or hoist is operating at rated capacity has been taken as the required half hour rating of the motor. This means that the equivalent continuous load (for the same average temperature rise) amounts to 40 or 50 percent of the half hour rating. Owing to its ability to dissipate more heat, the continuous capacity of a ventilated motor in sizes commonly used in crane work is some 40 to 50 percent of its quarter hour rating. For general crane service, therefore, the quarter hour rated ventilated motor will do the same work as the half hour rated enclosed motor.

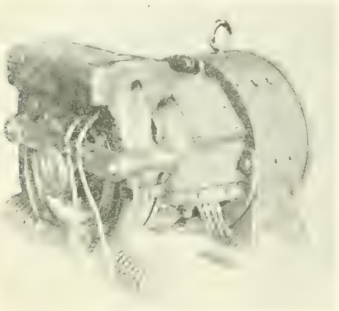


FIG. 6—VENTILATED CRANE MOTOR

EFFICIENCY

In a ventilated and an enclosed motor built for the same work, the core loss and the friction losses would be about the same. The I^2R loss would be somewhat greater in the ventilated motor. However, the loss due to the energy stored in the rotating parts during acceleration would be much less in the case of the ventilated motor, which would tend to counterbalance its greater I^2R loss. The loss in the control must be considered also, since the total loss in the motor circuit is the question of interest. Approximately one-half of the input during the accelerating period is lost in the starting resistance. In some cases, this may amount to one-quarter of the total input during the hoist period. When inching, nearly all the energy is lost in the grids.

COMPARATIVE TEST RESULTS

To bring out the different heating characteristics a number of tests were taken for direct comparison on a totally enclosed motor rated at 7.5 hp, 230 volts, 700 r.p.m. ½ hour, 50 degrees C and a ventilated motor rated at 7.5 hp, 230 volts, 800 r.p.m. ¼ hour, 50 degrees C. In each case temperature runs were taken for different periods, starting cold, to determine the rating which could be obtained with a 50 degrees C. temperature rise. The results of the test are shown in Fig. 5. The tests indicate a smaller capacity for the ventilated motor, for runs of short duration, but show that it has as much capacity as the enclosed motor or even a greater capacity, for runs lasting several hours.

VENTILATED CRANE MOTORS

A line of motors designed to secure the advantage of greater capacity made possible by ventilation is shown in Figs. 6 and 7. The frames are made of rolled steel in the smaller sizes, which gives lightness without sacrificing rigidity. In the larger sizes the frames are of cast steel and are split. The smaller motors are readily handled as a unit on account of their lightness. The bearings are of the shell type with oil ring lubrication. The shaft and bearings are massive and commutating-poles are provided so that heavy peak loads can be carried. The shaft has tapered ends to permit ready removal of the pinion or brake wheel.

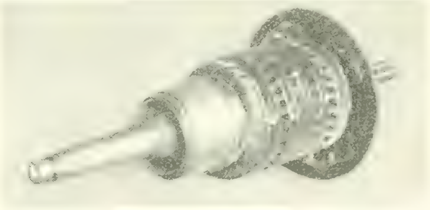


FIG. 7—MOTOR ARMATURE WITH FAN BLADES

Openings are provided in the lower half of the front bracket as shown in Fig. 6, to permit the entrance of air. In the lower part of the rear bracket, openings are provided for the escape of the cooling air. The openings are thus disposed so that falling objects cannot enter through them. As shown in Fig. 7, fan blades are attached to the armature to direct the air for effective ventilation. Removable covers on the upper part of the front bracket give access to the brush rigging and commutator for inspection. Back gear parts can be added readily and, if desired, a brake may be mounted on the front end of the motor, as shown in Fig. 6.

Switchboard Meter Connections for Alternating-Current Circuits-IX

Synchronizing with Lamps

J. C. GROUP

WHEN TWO or more sources of alternating current, such as generators, station bus-bars, lines, or any combination of these, are to be connected in parallel, it is necessary not only that the voltages be the same, but also that the maximum instantaneous voltages in corresponding phases of each source be in the same direction and occur at the same time. With these conditions present, the sources are said to be in phase or in synchronism and they may be connected together.

The conditions for synchronizing two single-phase generators are indicated in Fig. 92. Let it be assumed that generator *A* is running and switch *R* is closed so that power is being delivered to the line indicated by the leads *1-2*, and it is desired to connect generator *B* in parallel with generator *A*. As the voltage of generator *B* is equal to that of *A*, the correct time to close switch *S* is when the maximum instantaneous voltage of the incoming generator *B*, which is indicated by the arrow *b*, is in the same direction and occurs at the same time as the maximum instantaneous voltage of generator *A*, which is indicated by the arrow *a*. The two generators, when thus connected, supply power to the line *1-2* in the direction indicated by the arrows *d* and *e*, without any tendency to circulate current around the closed circuit through the armatures of the two machines, unless the characteristics of the generators are unlike due to differences in design or to non-uniform rotation of the prime movers. The vector relations of the generator voltages in the closed circuit through the two armatures are shown in Fig. 93, where E_A represents the voltage of generator *A* and E_B the voltage of generator *B*. These voltages are 180 degrees out of phase, and being of equal value, the vector sum is zero. There is therefore no voltage present to cause current to circulate between the machines. Any displacement of the voltage of one generator with respect to the other produces a voltage in the closed circuit through the two armatures, as is indicated by E_C in the vector diagram in Fig. 94, where the voltage of generator *B* is shown lagging by an angle ϕ behind the correct position for synchronizing represented by the dotted vector. The voltage E_C, which is equal to the vector sum of E_A and E_B, causes a current to circulate through the two armatures and this current tends to accelerate generator *B* and retard generator *A* and thus bring them back into synchronism.

The voltage conditions in Fig. 92 are incorrect for closing switch *S*, if the maximum instantaneous voltage of generator *B* is in the direction of arrow *c* at the same time that the maximum instantaneous voltage of generator *A* is as indicated by the arrow *a*. The two voltages are then in the same direction in the closed circuit through the two armatures, as is shown by the vector diagram in Fig. 95, and the vector sum of the voltages represented by E_C is equal to twice the voltage of one generator or the normal operating voltage of the system. Should the switch be closed under such conditions, the current that would flow would be limited only by the impedance of the two armature circuits and might destroy the machines. Therefore it is necessary that some means for synchronizing be provided whenever two or more sources of alternating current are to be connected in parallel.

When any number of polyphase circuits have the same direction of phase rotation, it is only necessary to synchronize with one phase, using the corresponding phase in all sources, and therefore in the discussions which follow only single-phase generators will be considered. This will be representative of one phase of polyphase generators or for any sources of alternating current other than generators.

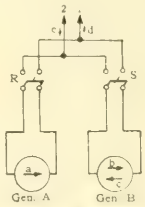


FIG. 92—CONNECTIONS FOR PARALLEL OPERATION

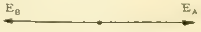


FIG. 93 VOLTAGES WITH GENERATORS IN SYNCHRONISM

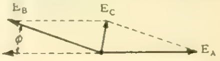


FIG. 94 GENERATOR B SLIGHTLY OUT OF SYNCHRONISM

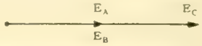


FIG. 95—GENERATORS 180 DEGREES OUT OF SYNCHRONISM

The simplest method of synchronizing is with lamps. The principles of this method can be explained in connection with Fig. 96, where generator *B* is to be synchronized with generator *A* and the two machines operated in parallel to supply power to the line *1-2*. Let it be assumed that generator *A* is running and the switch is open. The two lamps are connected across the poles of the switch as shown, when generator *B* is started. As the speed of the machine increases, the voltage will build up as soon as the field is excited and this voltage will be alternately in phase with and 180 degrees out of phase with the voltage of generator *A* until the speed of generator *B* becomes the same as that of *A*, when the voltages would remain in the same phase position with respect to one another. When the voltage of generator *B* is in phase with that of generator *A*, with reference to the line, no voltage is impressed on the lamps, as was explained by the vector diagram in Fig. 93 and the lamps would be dark, but when the voltages of generator *B* is 180 degrees out of phase with that of generator *A*, the voltages of the two machines operating in series, or double the voltage of one generator, is impressed on the lamps, and then burn at maximum brilliancy. Thus the flickering of the lamps give an indication of the phase relations. When the speed of the two generators is almost the same, so that the lamps flicker slowly, the switch may be closed when the lamps are entirely dark, for then the two generators are in synchronism. The voltage of each of the two lamps must be the same as the normal voltage of the circuit, or the voltage of one generator.

Connections commonly used on switchboards for synchronizing between any generator and bus with lamps are shown in Fig. 97. The single-phase generator circuits are typical for two of any number of generators and also for one phase of polyphase circuits. The synchronizing switches provide the necessary means for connecting the synchronizing apparatus to any one of the generators and also for disconnecting the synchronizing apparatus when not needed. The switches indicated are of the rotary type and are operated by a key which can be removed from the switch when in the *off* position so that one key is sufficient for an entire switchboard. The development of the switch shows the connections for the two positions. In the *off* position all the points are open, and in the *on* position points *1*, *2* and *3* are connected together and points *4* and *5* are connected together. The lamp indicated by a cross is usually located on the back of the switchboard to provide the extra resistance necessary in the synchronizing circuits. The lamps shown directly above the synchronizing switches are located on the front of the panels controlling the respective generators and are the ones to be observed while synchronizing. When a certain generator is to be synchronized and connected to the bus, which is already energized by one or more of the other generators, the synchronizing key is inserted in the synchronizing switch for that particular generator and the switch is moved to the *on* position. Then starting with the voltage transformer connected to the generator, the side of the secondary in which the fuse is shown is connected through points *3* and *1* and the lamp on the front of the panel to the incoming synchronizing bus *I*, from this bus through the lamp on the rear of the board to the running synchronizing bus *R*, and from this bus through points *4* and *5* of the synchronizing switch to the synchronizing bus *B* to which is connected the corresponding side of the secondary of the voltage transformer on the main bus. The other side of the secondaries of the two voltage transformers are connected together by the ground wire which completes the synchronizing connections. The flickering of the lamp on the front of the generator panel indicates when the generator is in synchronism with the bus. In Fig. 97 and also in almost all the figures which follow, the only connections shown are those necessary for synchronizing and the voltage transformers are indicated as being used only for that purpose, but in many cases the voltage transformers which are provided for meters may be used also for synchronizing.

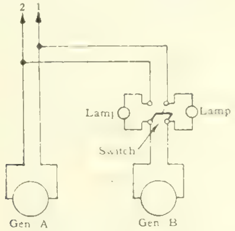


FIG. 96—SYNCHRONIZING BETWEEN TWO GENERATORS

Connections are shown in Fig. 98 for synchronizing between any two generators with lamps. This arrangement does not require a voltage transformer for the bus, but one for each generator is sufficient. The synchronizing switches, as indicated by the development, have three positions and two keys are used for operating them. One key when inserted in a switch will move it to the incoming position only so that points *1* and *2* are connected together, while the other key will move it to the running position only, so that points *2* and *3* are connected together. A switch must always be moved to the *off* position so that all the points are open before a key can be removed. One incoming key and one running key are sufficient for an entire switchboard.

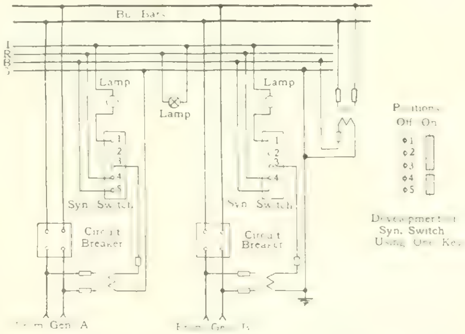


FIG. 97—SYNCHRONIZING BETWEEN ANY GENERATOR AND BUS

Assume that generator *A* is running and connected to the bus and it is desired to synchronize generator *B* with *A*. First the running key is inserted in the synchronizing switch for generator *A* and the switch is moved to the running position and then the incoming key is inserted in the synchronizing switch for generator *B*, bringing this switch to the incoming position.

Starting with the voltage transformer connected to generator *B*, the side of the secondary in which the fuse is shown is connected through points *1* and *2* of the synchronizing switch and the lamp on the panel for generator *B* to the incoming synchronizing bus *I*, thence through the lamp on the rear of the board to the running synchronizing bus *R*, and then through points *2* and *3* of the synchronizing switch on the panel for generator *A* to the corresponding side of the secondary of the voltage transformer connected to generator *A*. The flickering of the lamp on the panel for generator *B* indicates when the two machines are in synchronism. When several generators are connected to the bus and operating in parallel and it is desired to connect in another, it does not make any difference which one of the running machines is selected for synchronizing. Naturally, however, an operator would select a generator which was controlled from a switchboard panel most convenient to the panel from which the incoming machine is controlled. This method of synchronizing between machines requires one less voltage transformer than the method for synchronizing to the bus, but it requires two synchronizing keys and that two of the synchronizing switches be operated when synchronizing.

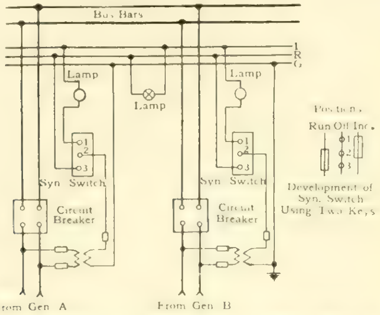


FIG. 98—SYNCHRONIZING BETWEEN ANY TWO GENERATORS

The use of lamps for indicating synchronism is quite satisfactory, but it is always difficult to judge exactly when the lamps are entirely dark. Several volts must be impressed across a lamp before the filament begins to glow, especially if the lamp has a carbon filament, and for that reason a synchronizing lamp may appear dark when actually the voltage of the incoming generator may be out of phase with the source to which it is to be connected by a considerable angle. Should the switch be closed under such conditions cross currents would circulate until the machine would come into synchronism. Furthermore, if the filament of a lamp should break while synchronizing, an operator might think that the incoming generator was in phase because the lamp was dark and close the circuit breaker at the wrong time. This danger can be averted, and the indication made slightly plainer, by reversing the secondary leads of one potential transformer, in which case the circuit breaker should be closed when the lamps are at their maximum brightness. With either connection, however, synchronizing by means of lamps is usually limited to small installations, in which the total amount of power involved is small and the inherent reactance of the generators is high. Synchronizing of larger capacity units is almost universally done by means of synchronoscopes.

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

To receive prompt attention a self-addressed, stamped envelope should accompany each query. All data necessary for a complete understanding of the problem should be furnished. A personal reply is mailed to each questioner as soon as the necessary information is available; however, as each queston is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply.

1918 **EFFICIENCY OF VERTICAL WATER-WHEEL ALTERNATOR**—When large water-wheel generators are tested at the factory, do the efficiencies obtained include windage, thrust bearing, and the upper and lower guide bearing losses? In other words, if the efficiency of a vertical water-wheel alternator is stated to be 97 percent, as found by the shop test, at a specified load and power-factor, does this mean that 97 percent of the power supplied to the generator shaft by the turbine will be indicated on the generator wattmeter at the switchboard? R.B.G. (MONT.)

All bearing, windage and electrical losses are included in the shop tests for efficiencies of water-wheel generators. This does not necessarily mean, however, that if such a test indicates, say, 97 percent efficiency, that 97 percent of its power input will be measured at its switchboard. This is true because the value of efficiency given is what is defined by the A. I. E. E. as a conventional efficiency, in which certain losses not directly measurable are approximated, and therefore the actual losses in the machine may vary slightly from those indicated by the conventional efficiency. R.A.M.

1919 **INDUCTION TYPE WATTHOUR METERS**—Will you kindly expain how induction type watthour meters are made to operate over a wide range of frequencies. Also what percentage of accuracy is attained? W.R.L. (N.Y.)

An induction type watthour meter is accurate only at the frequency for which it is designed and calibrated and therefore cannot be made to operate over a wide range of frequencies. A change of several percent in the frequency will produce a small error at unity power-factor conditions; but will produce larger errors with other power-factors. See Electrical Meterman's Handbook, p. 413 W.R.R.

1920 **BUS BAR ARRANGEMENT**—Fig. (a) shows a proposed arrangement for 600 volt, 60 cycle busses with a carrying capacity of approximately 5000 amperes. Please explain what effect an arrangement will have on the steel in the brackets. W.S.G. (N.H.)

Since all three busses of the three-phase circuit are within the same iron or magnetic circuit, there will be no effect on the iron from the electrical circuit. J.M.B.

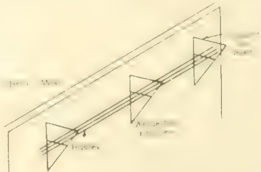
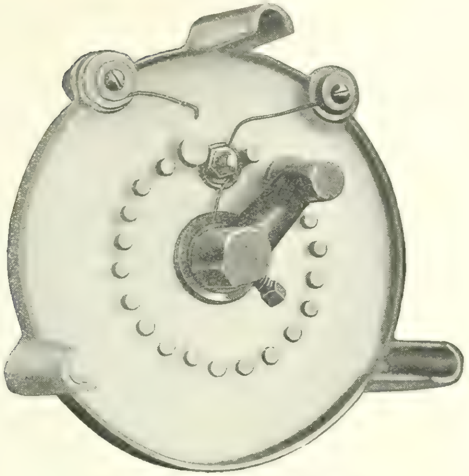


FIG. 1920 (a)



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NATIONAL SAFETY SECTION

BLAST FURNACES

(Continued)

The "blowing in" practice followed by the same company previously referred to is as follows:—

"(a)—The furnace, if one of several connected by a common gas main, should be isolated from the main by its water valve and goggle valves until filled and ready to light. Just before this time the goggle valve should be opened.

"(b)—The furnace should be lighted with its tuyeres and blowpipes in place, and bleeders and bells on top open and everything closed tight on downcomers and dustcatchers and gas lines, to the valves. Electric lighting at all tuyeres simultaneously by glowing coils is a good method. This is done by fanning the furnace slightly by a little air through mixer pipe and closing a switch which heats a coil in each blow pipe to a red heat. The coil is surrounded with excelsior soaked in carbon oil. After wood or charcoal in furnace is burning well the pressure of blast is gradually increased.

"(c)—When the gas is burning well, the tapping hole, after becoming hot, may be stopped with clay and coke dust in the usual manner. After this is completed the hot blast is put on gradually and increased, the amount and rate of increase being governed by local conditions.

"(d)—After the furnace has been on a sufficient time, so that all the green gas has disappeared and the gas lights can be lighted on top, steam can be turned in dust catcher, and the bells closed. It is customary at many plants when gas is not required immediately to allow the bells to remain open for a number of hours if it does not ignite on top. This is done so as to be sure that the gas is of good quality when brought down.

"(e)—After making sure that all air has been displaced from dust catcher and gas mains as far as the water valves (by carefully allowing the tapped air in the lines to escape slowly from doors or dust bells at points farthest from the furnace) and that the gas pressure is sufficient to overcome the main gas line pressure, the water valves may be opened and the bleeders closed. The use of steam, when bringing the gas down, to replace any air in downcomer or dustcatcher is an additional safeguard and is customary in many plants, but it can be dispensed with in some cases if sufficient precautions are taken.

"(f)—The same practice is followed in the case of gas going to stoves or boilers. Never permit a flame to come in contact with the gas if there is any possibility of a mixture of gas and air being present. Open doors slightly in the gas burners or gas flues (or a regular bleeding valve which is used in some cases) and wait until all the air is displaced from mains and there is a good continuous flow of gas. The gas can then safely be lighted. At many plants, as an additional safeguard, steam is also used to replace the air in gas flues to stoves and boilers."

Another member of the National Safety Council suggests the following:—

"To bring down the gas and to get it safely lighted under the boilers and in the stoves when blowing in a furnace, the steam should be turned into the dust catcher and gas main before the blast is put on the furnace. Keep all fires away from top of the furnace, and as soon as gas shows at the top after putting on the blast, close the big bell, leaving bleeders open. Gradually close bleeders after the gas begins to come in good volume (from 10 to 30 minutes should be ample) thus forcing the gas down and into the dustcatchers and out through into the gas mains. Keep all gas burners closed until gas pressure is sufficient to force gas out of every crack. Then open burner on boilers farthest from furnace and after a short time the pilot fire will light the gas without making any disturbance. Additional burners at boilers or stoves can be opened gradually as gas flow increases, and steam can be gradually shut off from gas mains and dust catchers."

Slacking the Blast.—Slacking the blast on a furnace should be done only by the furnace foreman, or under his personal direction. If the furnace is "hanging", the blast must be slacked only after the usual signal by whistle, which will give warning to everyone that the furnace is to be let down.

Breakdown of Blowing Engine In case or a sudden breakdown of blowing engines and it becomes necessary to lower the blast pressure, the big whistle at engine house should be immediately blown, to warn men at the furnace so they will flush the furnace and prevent slag coming back into the tuyeres.

Whenever it is necessary that men enter the air or steam cylinders of blowing engines, the following precautions should be taken:

(a)—Lock the throttle valve and attach sign "Danger—Man Inside".

(b)—Block one flywheel on front and back.

(c)—Block the crosshead on top and bottom.

(d)—Place a block (about 12x12x48 inches) in end of cylinder where men are working to block the piston.

Workmen should always make sure that these precautions are taken before they enter the cylinders.

OPERATING RULES FOR BOILERS

STARTING FIRES IN A COLD BOILER SETTING

If a boiler in a battery that is in service has been out of use for a time sufficient to permit all parts of the setting to become cold, or if it is a new boiler, the following method of starting it up is advised:—

The stop valve between the "goose neck" and the header should be tight; the drain pipes in the "goose neck" and the drain valve underneath the non-return valve should be open; and the connection to the steam gauge should be open and in good condition. Open the feed valve and fill the boiler gradually until the water level stands, between the first and second gauges of the boiler. Start a very light wood fire in the furnace, and have the damper in the stack practically closed. The escape of smoke from the setting will indicate any air leaks, unclosed doors or other defects which are undesirable when a boiler is in service. If any such leaks are observed they should be corrected before going further; in case of a new boiler, or a boiler with new brickwork in the furnace, this preliminary heating should be continued for a day or two if possible before going further. Continue the firing with gradual addition of coal, the damper being adjusted to the requirements until all the air is driven from the boiler, and steam is escaping from the proper channel.

A period of at least two hours should be occupied in bringing the steam pressure in the boiler up to the pressure in header; as stated above, if the boilers are new a longer time should be taken. While steam pressure is rising in the boiler, the gate valves between the boiler and the steam main should be opened slowly. This leaves the boiler still shut off from the main by the non-return valves. When the pressure on the boiler has reached the required pressure the non-return valve will open automatically, placing the boiler in connection with the main steam system.

Before commencing heavy firing, corresponding to the service in the remainder of the battery, lift the lever on the safety valve to see that it is free to act, and observe at the earliest opportunity whether this valve lifts at the allowed pressure of the boiler or under that pressure. At this time the stop valve in the boiler feed pipe near the feed main of the boiler house should be wide open, also the stop valve between the check valve and the boiler; the feed controlling valve should be adjusted by the water tender to an opening such as will provide the required water delivery.

CHECKING FIRES

The practice of checking fires by opening fire doors so as to permit an inrush of great quantities of cold air into the boiler setting and to the stack is bad from an economic standpoint, and subjects the boiler and setting to undesirably rapid changes of temperature. Instead of this, ash doors or other draft supply should be closed, and, if further checking is necessary, dampers should be closed. Finally, if necessary, open fire doors gradually.

BLOWING OUT BOILERS

The bottom blow-off should be used at least once every twelve hours, the valves in the blow-off connections being left open for a period of one-half minute or longer, depending upon the character of the feed water supply. A boiler should not be emptied before the setting has cooled.

TURNING STEAM INTO EMPTY SECTIONS OF PIPING

Steam should always be admitted to empty piping *very* slowly. If any portion of piping has remained unused for an hour or more it is important that it be completely drained before steam is again turned into it.

(To be continued)

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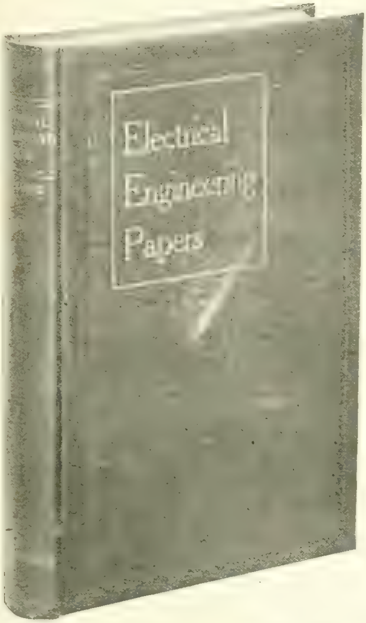

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NEW A.E.R.A. OFFICERS

At the annual convention of the American Electric Railway Association of Atlantic City, October 11-15, the following officers were elected for the American Association: President, Philip Gadsden, president, Charleston, South Carolina, Consolidated Company; 1st vice-president, R. I. Todd; 2nd vice-president, P. J. Kealy; 3rd vice-president, Britton I. Budd; 4th vice-president, C. D. Emmons. Mr. W. G. Gove, of the Brooklyn Rapid Transit Co., was elected president of the Engineering Association. Mr. R. P. Stevens, president of the Pennsylvania-Ohio Electric Co., was elected president of the Transportation and Traffic Association.

PERSONALS

Mr. W. K. Dunlap has been elected acting vice-president of the Westinghouse Electric & Mfg. Company with headquarters at the East Pittsburgh offices.

Mr. S. H. Abbott, formerly of the Baltimore service department of the Westinghouse Electric & Mfg. Company and during the war an officer in the engineer corps in France, has recently returned from a trip to France where he installed two 122 000 volt outdoor substations at Luchon and has now taken up work with the Westinghouse International Company with headquarters at East Pittsburgh.

Mr. J. H. Klinck, formerly of the Atlanta district office of the Westinghouse Electric & Mfg. Company and during the war a major in the construction division of the U. S. Army, has returned to the Westinghouse organization in the general sales department with headquarters at East Pittsburgh.

Mr. H. B. Joyce, formerly power engineer of the United Electric Light & Power Company of New York and during the war a major in the construction division of the U. S. Army, has entered the employ of Johnson & Benham, Inc., Engineers, with offices at 150 Nassau St., New York City.

Mr. Frank Thornton has been appointed manager of the electric heating department of the Westinghouse Electric & Mfg. Company, and will have charge of the design and development of heating apparatus manufactured by the Westinghouse Electric Products Company at their Mansfield works.

Mr. H. W. Hough, chief electrical & research engineer for the Cleveland Electric Illuminating Company, has resigned to join the staff of the Daniel M. Luehrs Company, Consulting & Construction Engineers, of Cleveland, Ohio.

Mr. C. A. Moore, superintendent of electrical department of the Cambria Steel Company of Johnstown, Pa., has resigned to become superintendent of power plants of Berwind-White Coal Company of Winber, Penna.

Mr. H. L. Barnholdt has been appointed section engineer in charge of large alternating-current mill and marine motor design in the motor engineering department of the Westinghouse Electric & Mfg. Company.

Mr. Morse Dell Plain, vice-president and general manager of the Northern Indiana Gas & Electric Company, was elected president of the Indiana Electric Light Association at its recent convention. Mr. Dell Plain was with the Westinghouse Company for about five years and later was power engineer for the Syracuse Lighting Company.

Professor A. S. Langsdorf, of the department of electrical engineering, Washington University of St. Louis, has resigned to become production manager of the Crunden-Martin Mfg. Company of St. Louis.

Standard Underground Cable Company, Pittsburgh, Penna., has just issued its bulletin No. 740-1 on joints and jointing materials. This includes instructions for making joints on lead covered cables, including the method of filling the joints with insulating compound.

The St. Louis Brass Co., St. Louis, Mo., are placing on the market their "Brasco" switch extensions which are made to attach to junction boxes or to screw to ceiling and are used where an individual switch is desired to control a single unit. Either pull or pendant switches may be used. A leaflet describing these will be sent on request.

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The Westinghouse Electric & Mfg. Company has secured a controlling interest in The International Radio Telegraph Company which concern enjoys the patent rights under the inventions of Professor R. A. Fessenden, some of which are the most important and controlling patents in radio communication. The Electric Company will take up the manufacture and sale of wireless apparatus. The officers of the Radio Company are: Guy E. Tripp, Chairman; E. M. Herr, President; S. M. Kintner, Calvert Townley and H. P. Davis, Vice-presidents. Mr. M. C. Rypinski has been placed in charge of all radio sales activities and L. W. Chubb has been appointed manager of the radio engineering department.

NEW BOOKS

"Industrial Electrical Measuring Instruments"—Kenelm Edgcumbe. 414 pages, 260 illustrations, Published by D. Van Nostrand Co., Fore sale by THE ELECTRICAL JOURNAL, Price $5.00

This is the second edition of this work by an English author and has largely been rewritten and expanded. The mathematics used is of the simplest type, vector diagrams being used where suitable. Line diagrams showing working principles have been used in place of the more usual photographic views. The sections which have been especially enlarged are those dealing with induction instruments, current and voltage tranformers, graphic instruments, power measurements and constructional details. A very extended discussion on errors and accuracy is included in the introductory section. A long discussion is also included on pyrometers, a subject not usually included in books on meters; also an extended discussion on instrument transformers. The crest voltmeter is also described.

"Theory and Calculation of Transient Electric Phenomena and Oscillations"—Chas. P. Steinmetz. 696 pages, 113 illustrations. Published by McGraw-Hill Book Company. For sale by THE ELECTRIC JOURNAL, Pittsburgh, Pa. Price $6.00.

This is a third and enlarged edition of this work originally published in 1909. During the past ten years the study of transient phenomena has been greatly extended. The development of the oscillograph has also aided in experimental work along this line. An entirely new part, section five, comprising six chapters has been added under the heading "Variation of Circuit Constants." Under this heading such phenomena as the flattening of steep wave fronts, wave decay in transmission lines, etc., are thoroughly discussed. In section four a chapter has been added on the relation of direct current and alternating current to the general equations of the electric circuit. A new chapter is devoted to impulse currents, that is, non-periodic or transient currents. In accordance with the international convention, the method of symbolic representation has been changed from the time diagram to the crank diagram.

"The Petroleum Handbook"—Stephen O. Andros, 206 pages, 48 illustrations 17 tables, size 4-1/4 by 7-5/8 inches. Published by Shaw Publishing Company, 910 South Michigan Ave., Chicago, Illinois. Price $2.00.

This book will be helpful to those desiring to be informed concerning the petroleum industry. The initial portion is devoted to geological principles and theories, followed by a chapter on exploration for oil and gas, methods of petroleum refining, natural gas and its products, method of marketing petroleum products, gasoline specifications and the economic utilization of petroleum in which are outlined the methods of an individual corporation in refining crude petroleum and distributing the products to the ultimate consumer.

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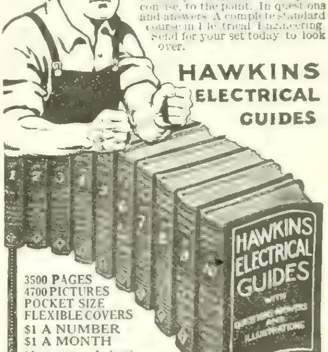

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THE ELECTRIC JOURNAL

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The Oscillograph

Since the early days of alternating-current machines, efforts have been made to get records of actual wave shapes. The rotating contact maker, which momentarily connected a voltmeter to the generator at a controllable point in the wave, was the commonly used device twenty years ago. By this means a sort of average of a number of successive waves was obtained but the result was rather crude. Nothing in the way of transient phenomena could be investigated by such a device.

The original refinement of the galvanometer to enable it to follow individual waves and transients accurately up to an ample frequency must be credited to Duddell. Cumbersome as the earlier oscillographs were, they permitted the obtaining of hitherto inaccessible data on the electric circuit. At present no investigation of the general characteristics of an electrical device by which any alteration of the electromotive force can possibly be produced is complete without the taking of oscillograms.

In this issue Mr. Joseph W. Legg describes some commercial applications of a new design of portable oscillograph. As Mr. Legg shows, one of the important uses for the oscillograph is the investigation of transient phenomena, such as the closing and opening of circuits, the effect of short-circuits and similar disturbances. Portability of the apparatus and its self contained character are of obvious convenience. To any one who has had to operate oscillographs in the past, however, a noteworthy feature is the elimination of the arc lamp with its heat, sputter and periodical adjustments, to say nothing of its treacherous disposition to shift its arc, and fail to give a beam from the mirror when needed.

This feature of the substitution of a tungsten filament lamp for an arc is a decidedly novel and convenient one and adds greatly to the reliability of the device. The expedient of impressing on the lamp a voltage greatly in excess of normal for an exceedingly short period and thereby obtaining a light comparable to that of an arc is daring and ingenious. The beauty of it is that the lamp does not burn out until thousands of exposures have been made.

Another indication of the reliability of the device is that Mr. Legg has felt it safe to take many records at distant locations, and then bring his films and apparatus home before developing to see the results. Numerous other conveniences for use in the field are described by Mr. Legg which show that as the demand for refined devices becomes more pressing it is met by improved designs.

R. P. JACKSON

Abnormal Motor Voltages

An article on the "Effect of Voltage or Frequency Variation on Induction Motor Characteristics", published in the JOURNAL for March 1917, proved so useful to operators of industrial motors that numerous requests have been received for a similar article on direct-current motors. Such an article, by Mr. M. S. Hancock, is presented in this issue. It is interesting to compare the effect of a change in voltage on an induction motor and on a shunt or compound motor; and also to carry the tendencies illustrated by Mr. Hancock to their logical limit, and see what effect will be produced by an extreme change in voltage.

Electrical apparatus is capable of operating under a wide range of conditions. For example a direct-current motor will operate over a range of voltage, from less than half of normal up to a considerable overvoltage. To be sure it may not pull as much load as it was designed for, certain parts of the motor will tend to overheat and the operating characteristics in general will suffer with any material departure from rated voltage. Nevertheless it will continue to run and pull a fair proportion of its rated load.

Regular operation under abnormal conditions should not be tolerated, as the motor is apt to suffer permanent damage, yet emergencies sometimes make it desirable to know just how far it is safe to depart from normal operation and what part of rated load a motor can carry without injury at, say, a materially reduced voltage. This depends to a considerable extent upon the design of the particular motor, as some motors will stand more abuse than others. The general trend of changes in operating characteristics produced by abnormal conditions is, however, fairly constant. This trend is explained fully for what may be considered a typical average industrial motor by Mr. Hancock, who has plotted curves showing the general effect of a 20 percent increase or decrease of voltage on speed, efficiency and the various losses in the motor.

Twenty percent probably represents as wide a variation of voltage as should ordinarily be permitted for anything like regular operation; as well as the maximum overvoltage that should be permitted for an average motor, even under emergency conditions. The penalties exacted by operation under extreme overvoltages—heating of field coils, possibility of flashing, mechanical strains produced by excessive speed—are much greater than those due to undervoltage, which consist merely in the necessity for reducing the horsepower rating, in poorer speed regulation and in slightly impaired commutation.

CHAS. R. RIKER

Air Brakes in Electric Traction Service

S. W. DUDLEY
Chief Engineer,
Westinghouse Air Brake Company

IT HAS been well said that the fundamental purpose of a railroad is to save time. The greater the traffic capacity of a given right-of-way in ton-miles or passenger-miles per unit of time, the more time is saved and the greater the value of the service.

Increased traffic capacity can be secured in many ways. A vast amount of engineering consideration has been given to improving power plant, transmission and rolling stock equipment and to securing increased speeds, capacity or number of cars. But high speed, frequent service, and large capacity units bring with them penalties as well as premiums.

The maximum traffic capacity results when the maximum number of maximum capacity cars are handled at a maximum speed. Where frequent starts and stops are to be made, maximum traffic density would be obtained if the acceleration to maximum speed could be instantaneous and this maximum speed held uniform until the next stop, the deceleration then being instantaneous.

It is the function of the power plant, of the transmission line and of the motor and control equipment to approach, as nearly as may be practicable, the ideal acceleration and running characteristics. Is it not evident then, that the deceleration or braking period is equally important? The brake, therefore, is something more than a safety device, necessary for protection against emergencies. It is as truly a high speed, maximum traffic device as the motors or the power station, and its functions in this direction, though perhaps less vital than its safety features, are more directly influential in building up the traffic capacity of a railroad property.

A heavy city car, running at 25 miles per hour on a level tangent might drift for a mile before coming to a stop, if no brakes were available. Would any railroad care to compile its schedules or provide its claim department with data on the basis of such a braking distance? Until the ability to stop is assured, the unwisdom of starting is obvious. The power plant, transmission, road bed and rolling stock are sources of danger rather than sources of dividends, unless means are provided for the adequate control of the car after it is in motion.

How, then, has it happened that the brake has attracted relatively so little engineering attention on the part of its users? Is it because of its humble position, its severely plain lines, its lack of display, its comparative freedom from the effects of external and internal disturbances? Possibly—but perhaps chiefly because of its ruggedness, its "overload capacity" and the fact that it has always approached much more nearly to its ideal of zero *deceleration* time than the ideal zero *acceleration* time has ever been approached. For example, in subway service an acceleration rate of 2 miles per hour per second average up to 30 miles per hour would be remarkable, whereas braking rates of 2.5 miles per hour per second are common for ordinary station stops and 3.5 miles per hour per second for emergency stops.

A consideration of all that is involved in the facts herein referred to justifies the statement that, from the standpoint of convenience, promptness, economy and safety in the handling of traffic—and these are the elements vital to the success of any transportation business—the brake is the most vital factor in the problem of transportation. It permits the utilization of existing motors, rolling stock and track to their maximum capacities and makes practicable and profitable the adoption of improvements in these directions that otherwise could not be justified.

The air brake has performed a part in the development of transportation in this and foreign countries which, with the exception of the locomotive, is unequaled by any other mechanical appliance. Without it, the modern locomotive would be uncalled for, the present high speeds would be impossible, and the handling of freight trains of even one-third the present length and capacity would be impracticable.

Fortunately it has been found possible to provide rugged and automatic apparatus, adequate for this service and capable of doing its duty while the engineer pays attention to other matters not so well able to take care of themselves.

This is as it should be. Just so far as a device is capable of the continued efficient performance of its intended functions, without attention on the part of the user, so far is it free from the variables of the human element.

But there are some distinctions, some limitations, some ranges of capacity and some obligations which must not be overlooked by the engineer who has occasion to consider the brake as a whole, or in any detail, in its bearing upon a transportation problem.

For example, the terms "brake" and "air brake" are often confused. It is sometimes presumed that because a car is fitted with a brake valve, or a triple valve, or an air compressor, it is thereby provided with a complete, effective and adequate brake. A moment's consideration will show that these, while necessary conditions, are not sufficient. A brake valve without any supply of compressed air would be useless. A triple valve on a car without brake shoes or a complete brake installation on a car running on rails of ice would be powerless to control the car.

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*Revised by the author from papers presented before the Baltimore Section, A. I. E. E. and The Westinghouse Club.

In other words, a brake is not complete until it includes the means for creating, controlling and utilizing the primary source of retardation, be it the force of compressed air or otherwise, so that it can retard or stop the movement of the vehicles. The failure of any one of the elements in the complete system, from the air compressor to the rail upon which the car runs, to contribute its proper share in the final result, will correspondingly lower or destroy the effectiveness of the system as a whole. The part played by the more obvious elements, such as the brake valve, triple valve or brake cylinder, is readily recognized, while equally important but less obvious elements such as the brake rigging, the brake shoe or the rail are often overlooked.

The elements comprehended in the term "brake" involve so many important considerations that some restrictions and eliminations are necessary. Let us then limit this review, to the air brake proper and further to a brief survey of the typical air brake equipments which have been developed to meet the requirements of the distinctive classes of electric traction service, viz:—

I—Light City Service—Single car or motor and trailer.
II—Heavy City and Interurban Service—Single car or short train.
III—Subway, Elevated and Suburban Service—Rapid transit train, rarely single car.
IV—Electric Locomotive Service—Single or multiple-unit.

Just as different motor and control equipments would be required to meet the needs of these different classes of service, so also the braking requirements of each class differ.

The air compressor, compressor governor, main reservoir and cooling pipe are common to all types of air brake equipments; while not always the same in type, their variation is along somewhat different lines than the classes of brake equipments.

Air Compressors of various sizes and types are used, according to the quantity and pressure of compressed air to be supplied, the type of drive to be employed, the installation conditions and so on. Except with respect to the compressed air requirements, the compressor characteristics are only indirectly related to the air brake proper.

Compressor Governing Systems are of two kinds, according to whether the cars always run singly or in multiple-unit. For strictly single-unit, single-compressor service a governor, consisting of a switch portion, suitable for opening and closing the circuit to the compressor motor and a pneumatic portion for opening this switch at a predetermined maximum and closing it at a predetermined minimum main reservoir pressure, is sufficient.

For multiple-unit service, or where two compressors are used on a single vehicle, the maximum compressor capacity and the most uniform division of the labor of compressing the air required are secured when all the compressors are caused to operate simultaneously and deliver into a common main reservoir system. The main reservoir systems on each vehicle are connected by a main reservoir pipe running the length of the train. Each compressor is controlled by an electropneumatic compressor switch, consisting of a switch portion operated by compressed air, as above mentioned, except in this case controlled by a magnet valve. The magnets of each compressor switch are connected in parallel between a common return (or ground) and a "synchronizing" wire running throughout the train, to which the governor on each car is connected. The operation of the pneumatic regulating portion of any one governor in accordance with the main reservoir pressure, will cause its switch to make or break the connection between the source of electrical energy and the "synchronizing" wire and so actuate all the compressor switches simultaneously and synchronize the operation of all the compressors. Thus, the labor of supplying the total quantity of compressed air required is divided among all the compressors in the train, according to their several efficiencies, the main reservoir pressures are equalized throughout the train and the advantages of a single governor control for all the compressors in the train are secured.

The Main Reservoir and Cooling Pipe systems vary in size and arrangement according to the installation conditions. It is common practice to divide the total reservoir volume on each vehicle into two reservoirs for convenience and better cooling effect, with

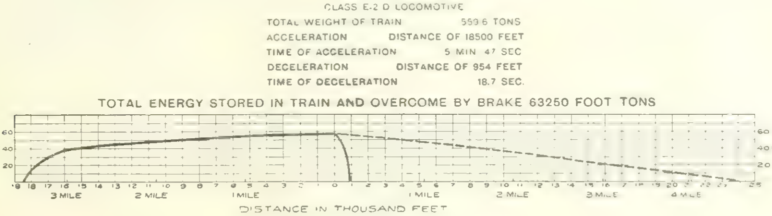


FIG. 1—THE REASON FOR A BRAKE

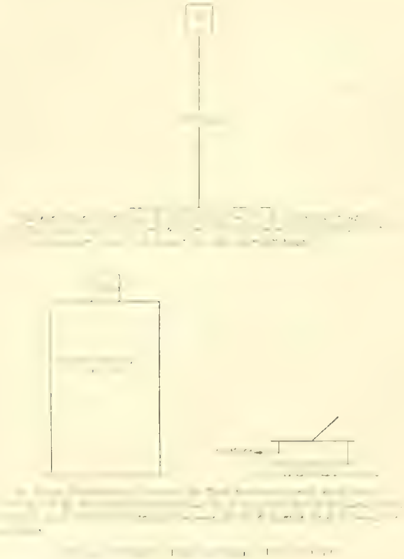
The broken line represents a stop without the use of brakes and was calculated by assuming 9.6 pounds per ton retardation due to wind resistance and journal friction on a level track. This curve shows that it took the train resistance nearly six minutes, and a distance of about three and a half miles to accomplish what the brakes accomplished in less than twenty seconds and within a distance of about one thousand feet.

radiating pipe between the compressor and first reservoir and between the two reservoirs. Within practical limits, the larger the radiating pipe, the better, both for dissipating the heat of compression and depositing the moisture in the compressed air before it enters the air brake systems and for preventing stoppage by frost and ice in extremely cold weather.

Coming now to the air brake equipment proper, the various types and their operative features are grouped according to the four classes of service above mentioned.

[illegible]

For such service the brake must be flexible, prompt in action, light and low in cost. Safety is a requirement that is taken for granted in all cases.



The Straight Air Brake has been and is still used for this service. With this brake, the compressed air is admitted from the main reservoirs through the motorman's brake valve to the pipe leading directly to the brake cylinder. While it, therefore, possesses the features of flexibility and simplicity to a maximum degree, it is not a safe brake in the sense that a brake with automatic features is safe, that is, a broken pipe or uncoupled hose will result in the loss of or the inability to apply the brake.

The Semi-Automatic Brake was devised to retain the simplicity and flexibility of the straight air brake and at the same time secure the protection and safety features of an automatic brake in case of accident to the piping. The ordinary service application and release of the brakes is the same as with straight air except that the air on its way from the motorman's brake valve to the brake cylinder passes through a device called an emergency valve. This emergency valve is inoperative during a service application of the brakes. But when an emergency application is made, or a pipe bursts or hose becomes uncoupled, the emergency valve moves so as to close the connection from the brake valve to the brake cylinder and let the main reservoir air directly into the brake cylinder.

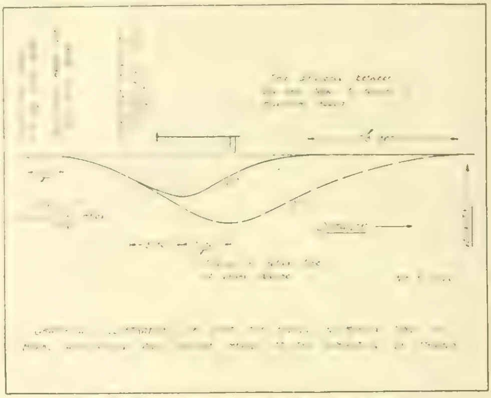
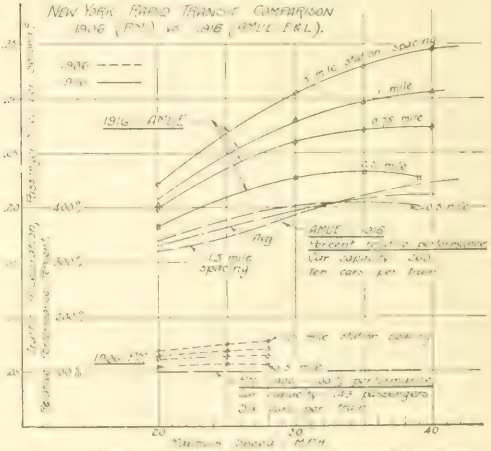


FIG. 3—TIME SAVING DUE TO REFLEX TIME

A more effective and responsive brake permits maximum (or drifting) speed to be maintained for a longer time before applying the brake (application reflex time) and a more prompt withdrawal of the retarding force when releasing (release reflex time), thus culminating in a materially greater time difference to regain maximum speed after a slow down than indicated by the direct time differences (reflex times) characteristic of the two brake equipments.

Two general types of the semi-automatic brakes are in common use, one for single car or motor trailer service, the other for motor cars running singly or in two car multiple-unit trains.

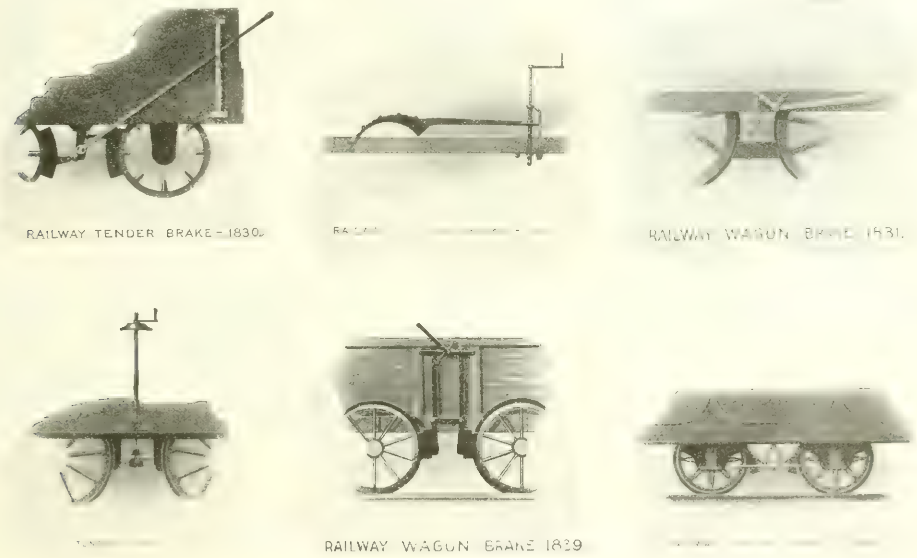


[illegible]

Modern train control equipment permits an increase of 50 percent in the number of longer trains it is possible to introduce into operation in a certain period of time, and the introduction of 350 percent more traffic handling facilities at a certain point than was possible in 1906.

For motor or motor trailer service, the admission of air to and exhaust of air from the brake cylinders in ordinary operation is directly controlled by the motorman's brake valve, as in ordinary straight air operation. For trains of two motor cars, each car supplying its own compressed air for braking purposes, a relay valve is interposed between the brake cylinders and the pipe connecting to the motorman's brake valve. This relay valve controls directly the admission of compressed air from the main reservoir on each car to the brake cylinder to apply the brakes and the exhaust of air from the cylinders to the atmosphere when releasing. The control of the relay valves on each car is from the motorman's brake valve in a manner similar to the system previously described.

In this way the compressed air required for braking purposes on each motor car is furnished by its own air compressor and thus approximately uniform compressor operation is secured without the use of a governor synchronizing system. The brake cylinder pressure is maintained against leakage and is uniform on all cars, independent of piston travel and, most important, a higher braking force is obtained in emergency than can be obtained in service applications, thus making it possible in case of danger for the motorman to stop his car more quickly than originally intended. This materially increases the safety factor of the equipment.


RAILWAY TENDER BRAKE—1830.

RAILWAY WAGON BRAKE 1831.

RAILWAY WAGON BRAKE 1829

FIG. 5—PRIMITIVE RAILWAY WAGON BRAKES

The Safety Car or One-Man Car service, recently inaugurated with such marked success throughout the country, has required the combination of several ingenious safety features with the "direct type" of semi-automatic brake and deserves more than passing mention.

In cities and towns, the particular business of a street railway, viz., quick and convenient transportation, is constantly subject to one omnipresent general manager—the man on the curbstone waiting for his car. How does he function? He wants *a car,* wants it *right now,* wants it to carry him, comfortably seated if fortune is kind, but at all events, carry him faster and more cheaply and conveniently than he could otherwise travel, and above all else *intact* to his destination. On every street corner one, two or a half dozen prospective patrons collect, not at stated intervals in conformity to a fixed schedule, but hit and miss, with no time to waste, and ready to walk or jump into a passing jitney if either is quicker than to wait for the car that may be coming by and by.

A realization that the harvest thus ready at hand would surely be reaped by anyone providing the convenient service demanded, led to the conception of a number of small light-weight cars running at intervals, variable at different times during the day, as the traffic might demand.

By thus providing frequent, convenient and rapid transit facilities, the first demand of the man on the curbstone was satisfied. Consequently he more frequently took the convenient car, where before he walked his two or ten blocks or jumped into a jitney. By using only one man to operate the car, collect fares and so on, the platform expense was halved and by the resulting material increase in the ratio of average earnings to average energy consumption and operating and maintenance expense, the investors' interests, as well as those of the man on the curbstone, were satisfied. By the very nature of the service, many more cars would be required to operate at certain times of the day than ever before, so the use of one instead of two men per car did not reduce, but rather increased the number of jobs to be filled. Thus the interests of the employees were satisfied. One further requirement remained, the subconscious but very real desire of the man on the curbstone to reach his destination in safety.

While, in his eagerness to "get there", he may take safety for granted, society through regularly appointed channels may intercede in his behalf with certain regulations safeguarding traffic; in accordance with which the proposed service, in order to be, must be safe. By the addition of certain safety and protective devices to the semi-automatic air brake, and by interlocking the brake with the controller, the circuit breaker, the sander, the doors, and the motorman himself, this final and critical requirement has been satisfied.

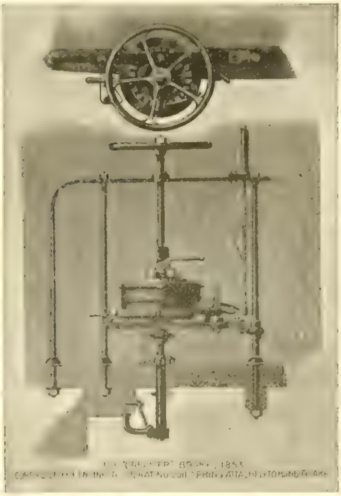


FIG. 6—THE CHAMBERS BRAKE, INTRODUCED IN 1853

This brake consisted of a large spiral spring attached to the brake shaft, at the end of the car, wound up by the brakeman immediately after leaving a station. Attached to the mechanism was a cord which ran through the train to the engineer's cab. When the engineer pulled the cord, the coil springs on each vehicle were released, and wound up chains leading to the foundation brake gear, thereby bringing the brake shoes against the wheels.

The safety car operated by one man affords the passenger more protection than the larger and heavier car operated by two men. First, the operator cannot leave his post without applying the brakes. In the event of impending danger, or if the operator is incapacitated or if, for any reason, he removes his hand from the controller handle without previously having the car under control, the power is automatically cut off, the track is sanded and the doors are unlatched ready to be opened, the brake applied in emergency and the car is stopped.

The brake valve and controller handles are interlocked indirectly, through the automatic safety attachments, so that while the brakes are held applied during a stop, or while the car remains standing, the removal of the operator's hand from the controller handle does *not* apply the brakes or throw out the circuit breaker. For the convenience and comfort of the operator, a foot valve is provided whereby he may prevent the automatic application of the brakes and throwing out of the breaker, so long as he continues to press down on the foot valve.

The control of the doors and of the sanders for ordinary service stops is incorporated in the brake valve. The sanders can be operated in any position of the brake valve handle. Sand is applied to the rails automatically by the emergency valve, when an emergency application is made. Only two handles, the brake valve and the controller handles, are therefore required for the complete control of the car and all of its operative devices. These safety features and conveniences are additions to the standard types of controller and brake equipments, so that the familiarity already acquired in their operation does not lose in value.

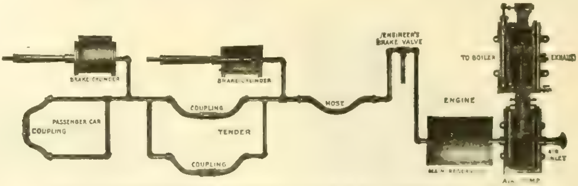


FIG. 7—WESTINGHOUSE STRAIGHT AIR BRAKE, INTRODUCED IN 1869

Compressed air was admitted from the main reservoir through the engineer's valve to the pipe leading directly to the brake cylinders on each car in the train.

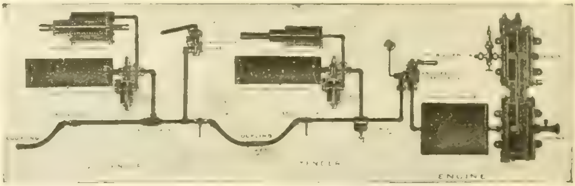


FIG. 8—WESTINGHOUSE PLAIN AUTOMATIC AIR BRAKE, INTRODUCED IN 1872

Any material depletion, from any cause, of the brake pipe pressure, either at the will of the engineer, by hose parting, leakage, or at the instance of the train crew, resulted in an application of the brakes. This was accomplished through the medium of a valve device called a "triple valve," and an auxiliary storage reservoir, which were added to the brake cylinder on each car.

With the higher rates of acceleration and deceleration, and with the greater frequency of service permitted by the safety car (which are impractical with the larger cars) faster schedules can be maintained and more satisfactory service rendered; thus increased revenues result through the increased traffic attracted. For example, in the first five days operation of safety cars on a line in a Southern State, hauling about 8700 passengers per day, the records show that:—

1—The average earnings per day increased 32.7 percent, of which about 5 percent was taken from competing lines.

2—The energy decreased from 3100 to 1650 kw-hr. per day; 47 percent saving.

3—The car-miles (scheduled) increased from 1295 to 1700 per day; 31.3 percent.

4—The car-hours (scheduled) increased from 153 to 179 per day; 17 percent.

5—The scheduled speed increased from 8.46 to 9.50 miles per hour; 12.3 percent.

6—Total passengers per car-mile, on corresponding days, 5.27 with 12-bench open cars and 5.16 with safety cars, which is practically the same number of passengers per car-mile at the reduced operating costs and increased service capacity noted above.

II—HEAVY CITY AND INTERURBAN SERVICE—SINGLE CAR OR SHORT TRAIN

On electric roads connecting the business and residential areas of cities or running between centers and suburbs, or passing through several towns, single car operation is likely to predominate, with occasional train operation. The flexibility and prompt response of the straight air brake is especially suited to single car service but it does not provide any automatic safety feature. Furthermore, when more than two cars are coupled together to run as a multiple-unit train, the straight air brake, even with the automatic emergency features, becomes unsatisfactory, because of the time element in application and release. For both reasons the automatic type of brake is required for train service.

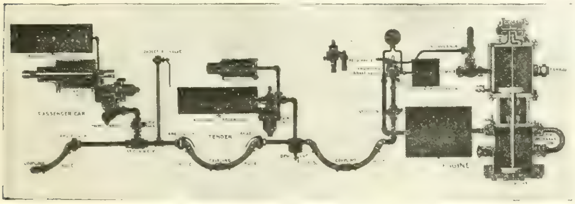


FIG. 9—THE WESTINGHOUSE QUICK ACTION AUTOMATIC BRAKE, INTRODUCED IN 1887

With the plain automatic air brake, the brake pipe reduction took place at only one point in the train. With the quick action automatic brakes, in emergency, air is automatically vented from the brake pipe on each car. This reduction is transmitted serially throughout the train, thereby reducing the time of full application and the length of stop.

The brake for such service should, therefore, permit the control of single cars with all of the protection of an automatic brake, but with the flexibility of manipulation of the straight air brake and should provide an automatic control for train operation with a minimum of readjustment. The brake developed to meet these requirements provides for the flexible, convenient "straight air" service operation on a single car (or on the head car of a train, if desired) entirely independent of the automatic features, which are held in reserve during "straight air" operation, ready to function with full effectiveness in case of need. The positions of the brake valve handle for securing this control are between the release and lap positions of the automatic brake control, making it convenient for the motorman to use either the automatic brake for train, or the straight air for single car service, according to circumstances.

The primary function of the brake equipment for this, as for any train service, is to apply automatically, in case of burst hose, broken pipe, opening of a conductor's valve and so on. While the service application and release is limited to a predetermined safe and suitable maximum for ordinary conditions, approximately 30 percent higher brake cylinder pressure can be obtained in emergency applications, in one-third the time, and it is then maintained, without reduction and against loss by leakage, up to the capacity of the compressor. Furthermore, this maximum maintained emergency brake cylinder pressure is insured, regardless of the conditions of the triple valve, by being controlled directly through the motorman's brake valve.

Another important safety feature is the ability to recharge the brake system as promptly as the brakes are released. This means that the brakes are ready for immediate re-application to full effectiveness in case of sudden need. The same means which permit this prompt recharging also permit the brakes to be released in a series of steps or graduations—an operation of great assistance in making quick stops smoothly and accurately, but not possible with the ordinary plain automatic brake.

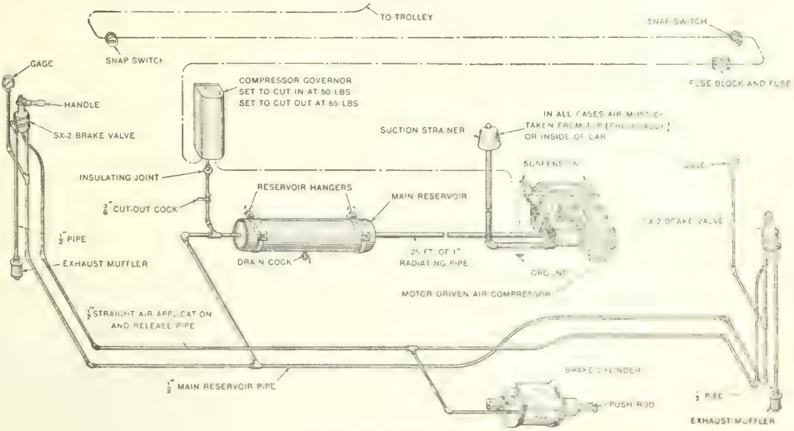
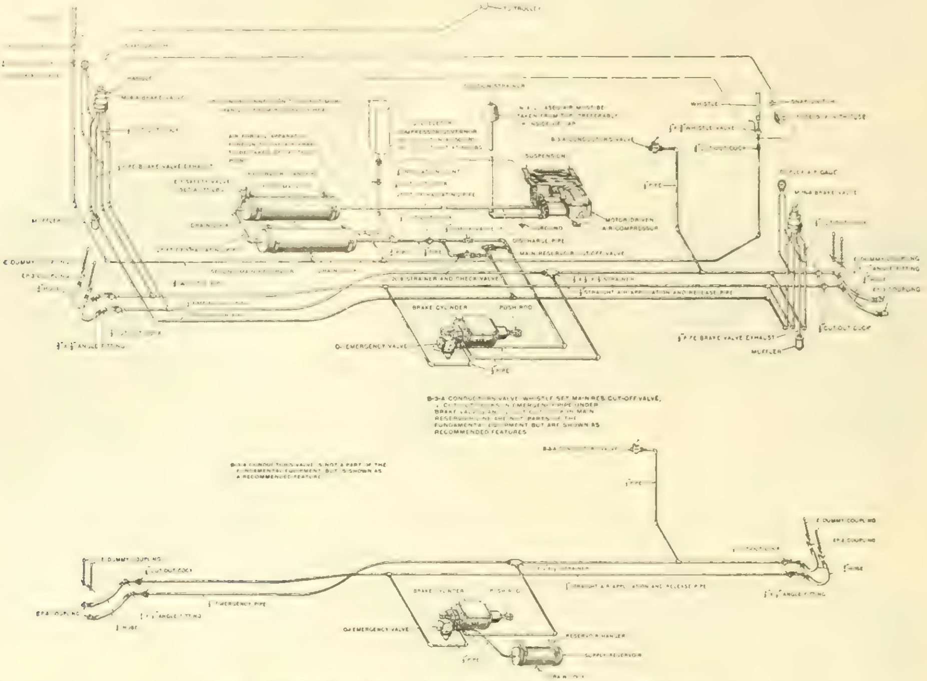


FIG. 10—STRAIGHT AIR BRAKE
Standard for low speed city service.

The plain triple valve (which has no quick serial emergency action) is used instead of the quick action triple valve, because on such short trains, not exceeding five cars, the effect of the brake valve venting the brake pipe to the atmosphere is sufficient to produce substantially as quick and simultaneous action of the brakes on all the cars in the train with plain as with quick action triple valves which vent the air from the brake pipe, serially, on each car. In emergency application, not only is 30 percent higher emergency brake cylinder pressure obtained in about one-third the time of a service application, but this high cylinder pressure is held without reduction until a release is made. This at first appears contrary to the principles established by the Galton Westinghouse brake trials in England in 1878-1879 to the effect that, as the speed of a train is diminished by continued brake action, the effectiveness of a given brake shoe pressure gradually increases, due to the coefficient of brake shoe friction increasing with decreasing speed. This principle remains as firmly established, today as when first demonstrated. But it is found that with the emergency braking percentages of 125 to 150 percent maximum in modern practice, (as compared with the 200 to 300 percent used in the Galton Westinghouse trials) and the amount of work done per unit of brake shoe bearing area, the abrasion and heating of the brake shoe surface is such that the coefficient of friction remains substantially constant for the major portion of the stop. The increase in coefficient of friction and consequently in retarding force for a given brake shoe (and brake cylinder) pressure, which invariably occurs when the speed decreases below 25 miles per hour, although considerable, either does not become high enough to cause the wheels to slide at all or not until so near the stopping point that what sliding does occur is not detrimental.



WHISTLE
SUSPENSION
MOTOR DRIVEN AIR COMPRESSOR
DISCHARGE PIPE
MAIN RESERVOIR CUT-OFF VALVE
STRAINER AND CHECK VALVE
STRAIGHT AIR APPLICATION AND RELEASE PIPE
BRAKE CYLINDER
PUSH ROD
Q-EMERGENCY VALVE
MUFFLER
PIPE BRAKE VALVE EXHAUST
CUT OUT COCK
ANGLE FITTING
DUMMY COUPLING
B-3-A CONDUCTORS VALVE
B-3-A CONDUCTORS VALVE, WHISTLE SET, MAIN RES. CUT-OFF VALVE, ... EMERGENCY PIPE UNDER BRAKE VALVE ... IN MAIN RESERVOIR ... ARE NOT PARTS OF THE FUNDAMENTAL EQUIPMENT BUT ARE SHOWN AS RECOMMENDED FEATURES
B-3-A CONDUCTORS VALVE IS NOT A PART OF THE FUNDAMENTAL EQUIPMENT BUT IS SHOWN AS A RECOMMENDED FEATURE
EMERGENCY PIPE
HOSE
RESERVOIR HANGER
SUPPLY RESERVOIR

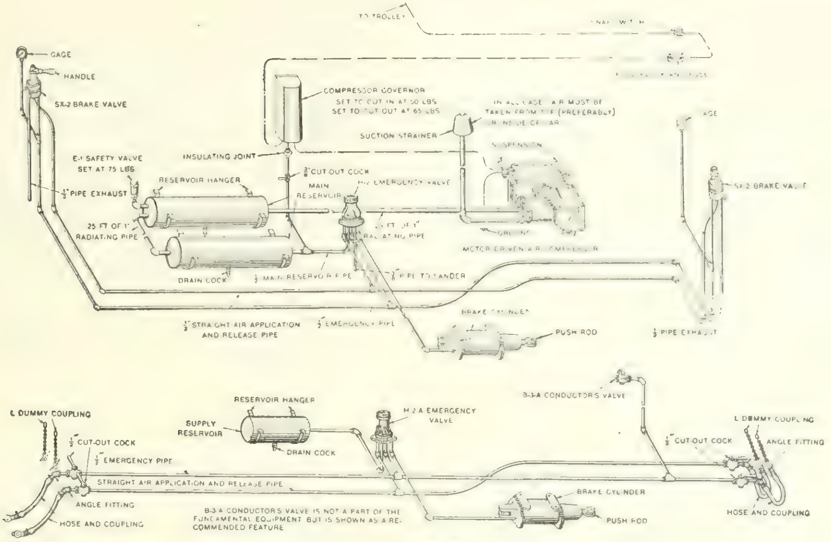
FIG. 11—SEMI-AUTOMATIC EQUIPMENT, TYPE D EMERGENCY VALVE

Standard for single car and two-motor car train service. The top view shows the equipment for the motor car and the bottom view for the trailer.

A significant fact in this connection is often not fully appreciated. It is better to take advantage of the maximum possible retarding force throughout the major portion of an emergency stop and risk sliding the wheels for the last ten or twenty feet, than to proportion the braking force so that the wheels will not slide at all, even on a bad rail, which may mean a collision when a safe stop could otherwise have been made. For these reasons, it has been found both desirable and

FIG. 12—[illegible] ENTRANCE [illegible] NEW YORK RAILWAYS COMPANY

Equipped with semi-automatic equipment shown in Fig. 11



TRAILER CAR

FIG. 13—FEATHERWEIGHT EQUIPMENT

Adaptable for changing over existing forms of straight air brake equipment, with minimum change, to include the automatic feature. The top view shows the equipment for the motor car and the bottom view for the trailer.

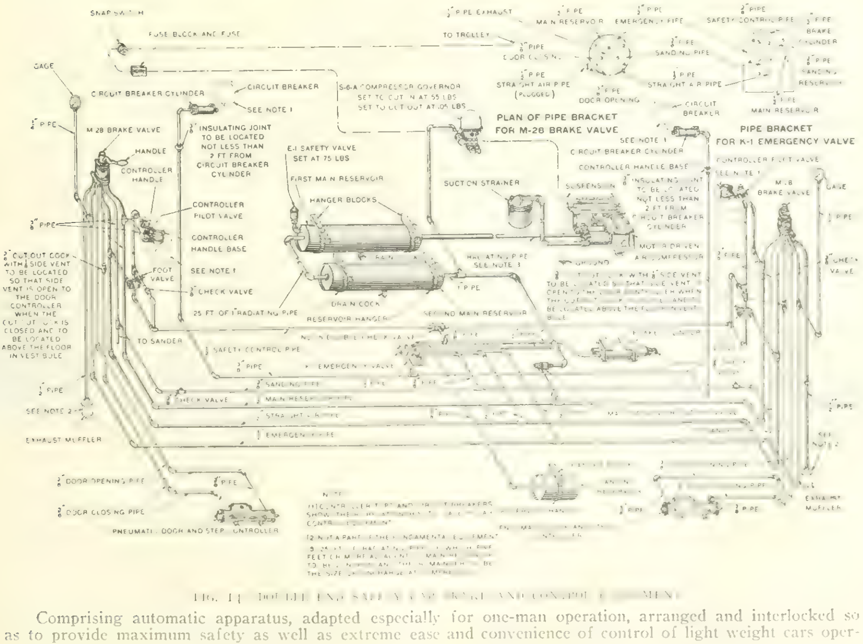


FIG. 14—DOUBLE END SAFETY CAR BRAKE AND CONTROL EQUIPMENT

Comprising automatic apparatus, adapted especially for one-man operation, arranged and interlocked so as to provide maximum safety as well as extreme ease and convenience of control of light weight cars operated singly in city surface line service.

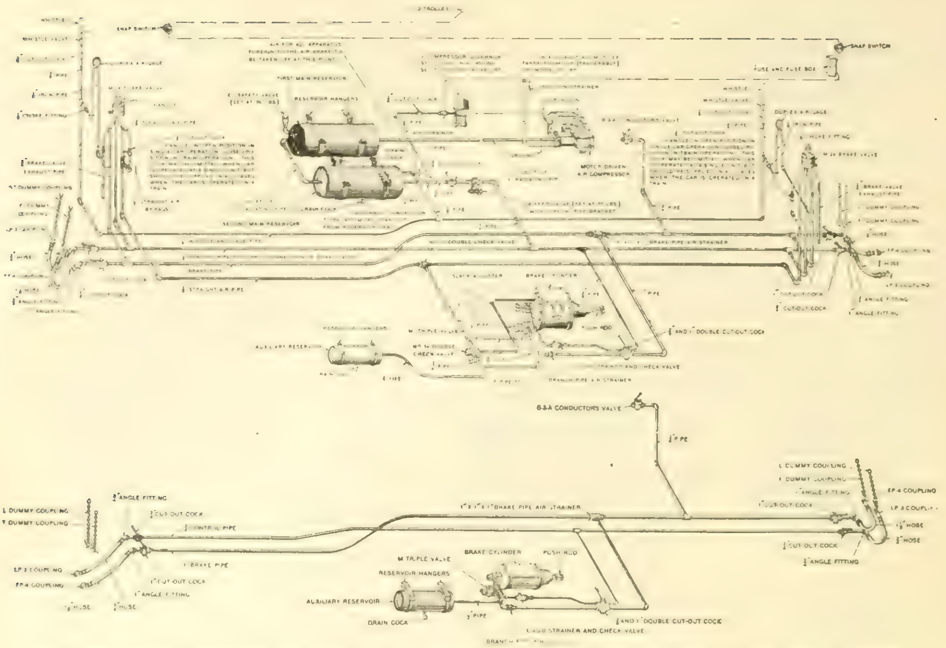


FIG. 15—COMBINED AUTOMATIC AND STRAIGHT AIR CONTROL, WITH REDUCTION LIMITING FEATURE AND GOVERNOR SYNCHRONIZING SYSTEM

For single cars or trains up to five cars in length, operating in both city and high-speed suburban and interurban service. The top view shows the equipment for the motor car and the bottom view for the trailer.

feasible to hold the maximum braking force obtainable in emergency applications without reduction, until the train is stopped.

Electric control of the brakes, although ideal and entirely practicable, has not appeared to be necessary or justified by the requirements of this service. It adds nothing to the effectiveness of the individual brake. Its only function is to save time in applying the brakes by eliminating the serial time element inseparable from an impulse transmitted pneumatically from car to car. Where trains are relatively short, therefore, pneumatic transmission is so nearly instantaneous that the stop is not materially lengthened thereby, nor is there sufficient slack or time element to cause objectionable shocks from this cause.

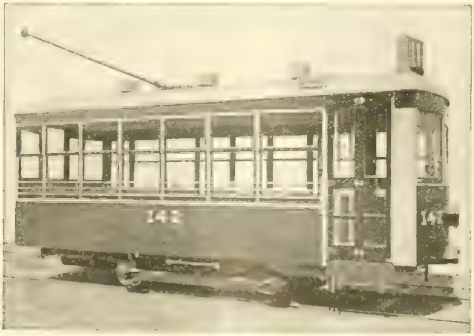


FIG. 16—STANDARD BIRNEY SAFETY CAR

Equipped with the safety brake control devices of the Safety Car Devices Company as shown in Fig. 14.

III—SUBWAY, ELEVATED AND SUBURBAN SERVICE—TRAIN—RARELY SINGLE CAR

When the carrying capacity of a given trackage is taxed to its limits, every means available for increasing the passenger miles per car becomes of prime importance and the value of such means then becomes apparent. Take the electrical control of brakes as an example. As has been said, this does not add anything directly to the effectiveness of the brake on any one car. It merely eliminates the serial application effect, inseparable from a pneumatically-controlled brake on a train of several vehicles. In doing this, however, it accomplishes two results which are of vital consequence

FIG. 17—THREE CAR TRAIN OF THE AURORA ELGIN AND CHICAGO RAILWAY

Equipped with the air brake system shown in Fig. 15.

in long train service, viz., the elimination of slack action between vehicles and the saving of the time and distance in making a stop through which the train would otherwise run while the pneumatic brake action was being serially transmitted from the head to the rear of the train. In other words, slack action is eliminated and the stop is materially shortened.

It is quite clear, however, that these features become of greatest value where trains are long and run on close headway with frequent stops and the traffic capacity of the road severely taxed. For these reasons the electric control has been found especially desirable for such service in the subway systems of Philadelphia and New York, and the Elevated of Boston, the Paoli Electrification of the Pennsylvania Railroad etc.

The electropneumatic brake system adds to the pneumatically-operated brake of the highest type certain advantageous features otherwise impossible of attainment, namely: simultaneous and uniform response of all the brakes in the train, which means the ability to obtain the desired results with the least skill and experience, regardless of the length of train; double protection against delays to traffic, due to brake failure, since the pneumatic brake is always in reserve ready for use, if required; maximum efficiency and safety due to simultaneous operation of all the brakes in the train, in both service and emergency application and the ideal flexibility of manipulation; economy in air consumption, and maintainance of brake cylinder pressure at will.

The shorter service stop thereby made possible means that power may be shut off sooner and the train allowed to drift for a considerably longer time before applying the brakes and making the stop at the same point. Thus, for the same power consumption, the electropneumatic brake makes it possible to maintain higher average speeds, shorter schedules and an increased traffic capacity with the same number of cars; or the same traffic capacity with fewer cars; or enables the same average speeds, schedules and capacity of road to be maintained as with a purely pneumatic brake but at the expenditure of less power.

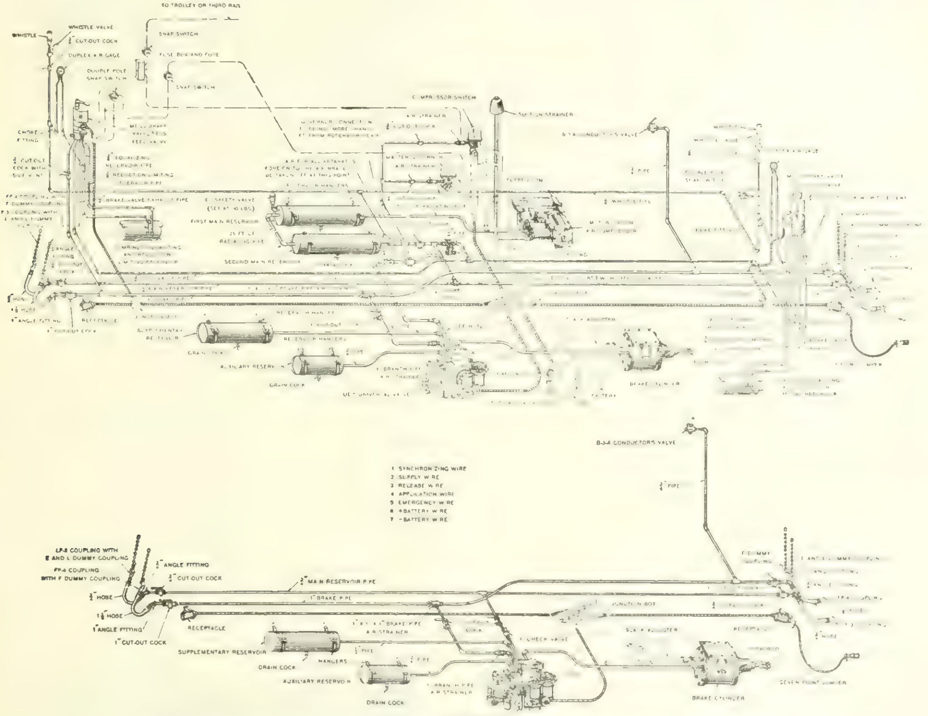


FIG. 18—EQUIPMENT FOR ELEVATED, SUBWAY AND HIGH SPEED ELECTRIC SURFACE LINES

Also for electrified divisions of steam railways. New York Interborough and Pennsylvania Railroad Paoli Electrification. The top view shows the equipment for the motor car and the bottom view for the trailer.

It should be borne in mind that the electropneumatic control of the brakes is a control only and that it must depend for its fundamental safety and protective features upon the pneumatic brake with which it is associated. The importance of improving the pneumatic brake to its highest degree before adding electric features is therefore evident.

The only forms of pneumatic brake for train service fifteen years ago were the quick action and the high speed brakes. The former employed the quick

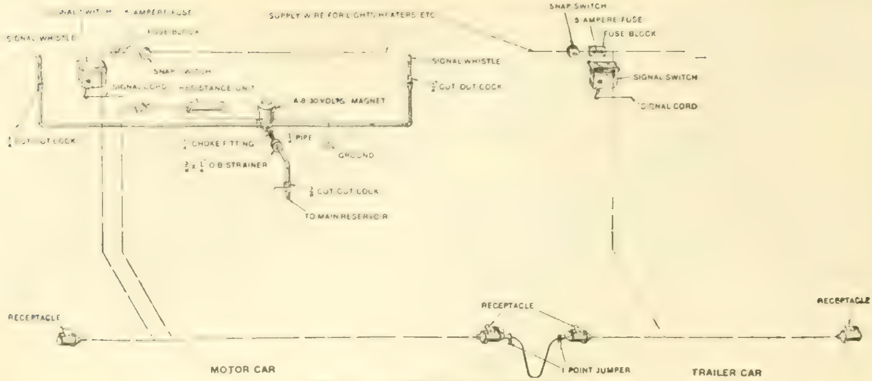


FIG. 19—ELECTRIC SIGNAL SYSTEM

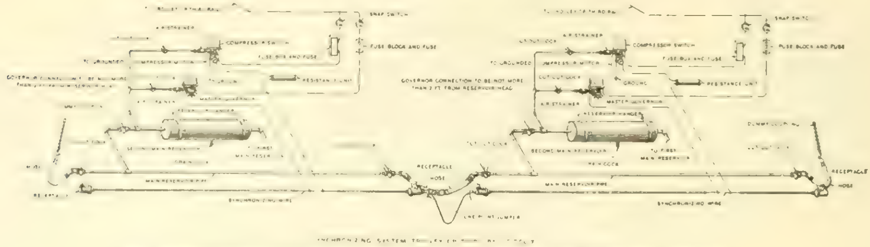


FIG. 20—GOVERNOR SYNCHRONIZING SYSTEM FOR TROLLEY OR THIRD RAIL CIRCUIT

action triple valve and 70 lbs. brake pipe pressure. It permitted the brakes to be graduated on, but not off. The release, once started, would continue until completed. On modern cars it would give a somewhat higher and quicker emergency braking force than in service applications, but the difference in cylinder pressure would not be more than five percent and the time to obtain its maximum a matter of four or five seconds on a train of ten cars.

The so-called high speed brake was the same as the quick action except for the addition of a high speed reducing valve and an increase in the air pressure from 70 to 110 lbs. per square inch. About 20 percent higher final service application pressure was permitted with this system and, in emergency, it reached about 40 percent higher pressure than in service, but this higher pressure was gradually blown down by the action of the high speed reducing valve to compensate for the increased coefficient of brake shoe friction at the lower speeds.

Modern rapid transit service, however, makes other demands upon the brake. It must be possible to graduate the brakes off as well as on. The full effectiveness of the brake must be available for a reapplication as soon as the brakes have been released, not once, but several times in quick succession. The service as well as the emergency application must be as nearly simultaneous as possible on all the cars in the train. The service and emergency functions of the brake must be so interlocked that an emergency application takes place when, and only when, it is intended. But it should always be possible to obtain quick action and emergency cylinder pressure at any time, regardless of previous manipulation.

FIG. 21—[illegible]

Equipped with [illegible] and [illegible] synchronizing systems, shown in Figs. 19 and 20. The trains on the West Jersey & Seashore Railroad are similarly equipped.

FIG. 22—[illegible] LOCOMOTIVE OF THE NEW YORK, NEW HAVEN AND HARTFORD RAILROAD

Equipped with the air brake shown in Fig. 23.

In emergency applications, it should be possible to produce from 50 to 100 percent higher brake cylinder pressure than in ordinary service applications, according to the limiting conditions of the truck and rigging construction, the road conditions and the service requirements, and this high emergency pressure should be held without blow down until released, in order to stop in the shortest possible time and distance. This should be obtained without increasing the brake pipe pressures above 70 lbs. and also without impairing the ability to release positively and promptly after such an application with 70 lbs. brake pipe pressure.

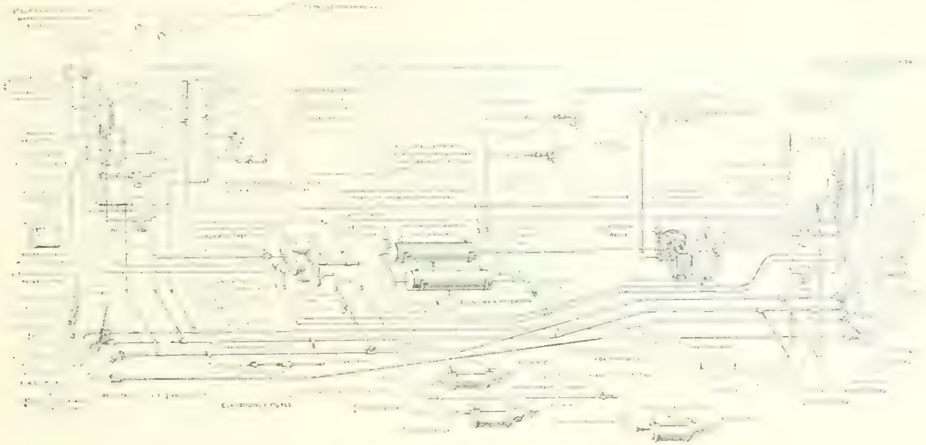


FIG. 23—ELECTRIC LOCOMOTIVE EQUIPMENT

While the reasons for most of the foregoing requirements are self-evident, the obtaining of a highly effective emergency application without exceeding 70 lbs. brake pipe pressure involves much more than may appear from the mere statement.

With 70 lbs. brake pipe pressure, the main reservoir pressure usually carried is 85 to 100 lbs. per square inch. To obtain the effectiveness of the modern brake with the old quick action triple valve would require an increase in brake pipe pressure from 70 to at least 110 lbs. and this, in turn, would require the adjustment of the compressor governor at 125 to 140 lbs. It is obvious that a maximum main reservoir pressure of 140 lbs. instead of 100 lbs. will result in more wear and tear on the compressors, higher temperatures, greater losses on account of leakage and larger compressors and motors. The brake system which takes advantage of the higher emergency pressures without necessitating a 40 percent increase in maximum main reservoir pressure is thus materially increasing the economy as well as the safety of the service.

The several operative features mentioned have been provided in various degrees by the installations on such roads as the Pacific Electric Railway, the Chicago Elevated Railways, the subways of Philadelphia, New York and Boston, the suburban service of the Pennsylvania, the Long Island, the New York, New Haven and Hartford, and the New York, Westchester & Boston Railroads, etc.

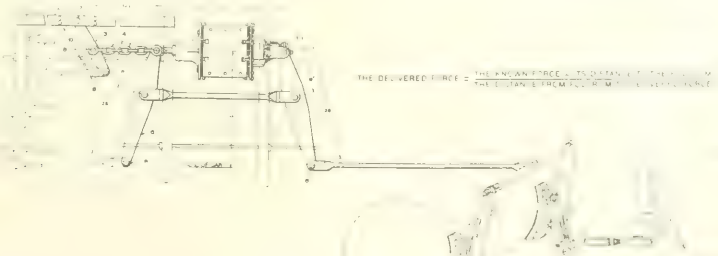

THE DELIVERED FORCE = THE KNOWN FORCE × ITS DISTANCE FROM THE FULCRUM / THE DISTANCE FROM FULCRUM TO DELIVERED FORCE

FIG. 24—[illegible]

The electropneumatic empty and load brake equipment of the New York Municipal Corporation Cars is a particularly interesting example because, in addition to its electric and pneumatic brake control functions, means are provided for varying the braking force automatically according to the passenger load, thus providing a uniform rate of retardation with empty, partly loaded and fully loaded cars. This is accomplished by means which automatically proportion the brake cylinder pressure to the weight of the car and load, according to the corresponding deflections of the truck equalizer springs. The automatic adjustment is interlocked with the car doors so that it is operative only when the doors are open. As the doors are always closed when the car is running and the adjusting mechanism is then inoperative, the very serious difficulties encountered with any adjusting mechanism subject to the vertical movements of the car body when moving over low track joints, frogs, switches and so on, are entirely eliminated. The same actuating mechanism is also utilized in connection with the motor control circuits to provide uniform acceleration at all loads.

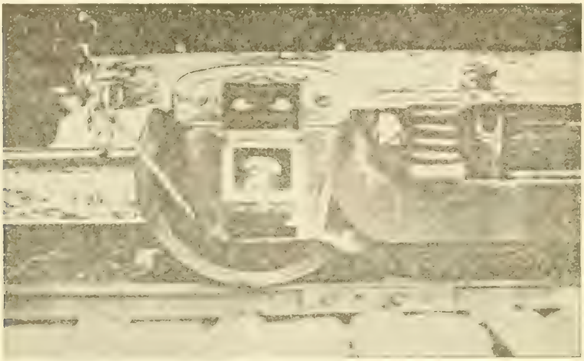


FIG. [illegible] REASONS FOR POOR BRAKES

Side strain on pedestals and tilted brasses resulting from single shoe brake.

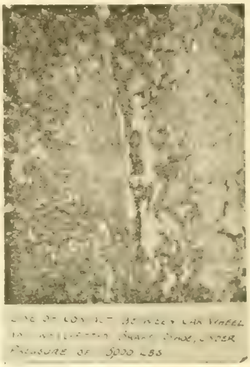


FIG. 27—WHERE THE WORK OF BRAKING IS DONE

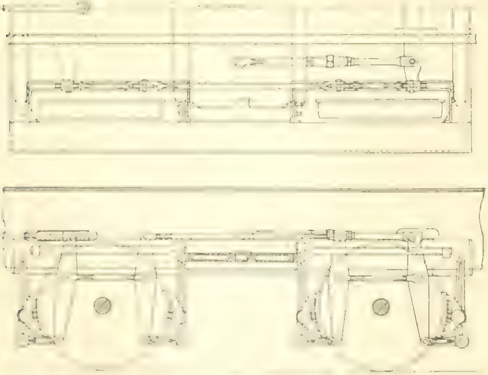


FIG. [illegible]

This type of brake equalizes the shoe forces on the wheel, reduces brake shoe wear, journal friction, hot boxes, unbalanced strains, on pedestals and shortens stops.

When the loaded car weighs approximately 50 percent more than the empty car (as in this case) the benefits of uniform acceleration and deceleration, independent of load, are readily appreciated.

A few years ago a prominent official of the Interborough Rapid Transit Company of New York stated that they were then carrying from 800 000 to 1 200 000 passengers a day in the subway, and that to go back to the air brake equipment used only four years previously would mean that 400 000 of these people would have to walk. It would be an utter impossibility to operate a sufficient number of trains over the road to carry them. This is mentioned as an example of the earning capacity of the modern brake for rapid transit service where speeds and close headway are of such importance as in subway and elevated service.

IV—ELECTRIC LOCOMOTIVE SERVICE—SINGLE AND MULTIPLE UNITS

The air brake equipment for electric locomotives, as well as the motor and control apparatus, must be suited to the service handled. This varies from the light yard or interurban express car locomotive to the large trunk line or heavy grade freight and passenger locomotives of which the Chicago, Milwaukee and St. Paul locomotives are leading examples.

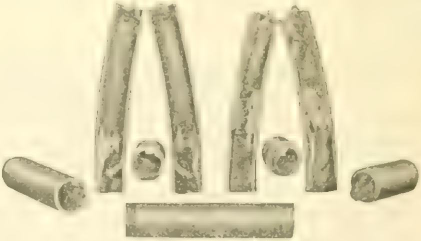


FIG. 28—STOPPED UP PIPES

Why the brakes sometimes do not operate as intended.

As the locomotive is primarily intended to haul or push trains, its brake must operate in harmony with the train brakes, the latter being controlled automatically or manually by the engineman through the aid of the air regulating and controlling mechanism in the locomotive cab. For light locomotives, used to haul short trains of freight or express cars over interurban or industrial tracks, the demand for compressed air, both in quantity and pressure, is not as great as for long train or high speed steam road service, the units are smaller and the service requirements generally less severe. The brake must, therefore, be automatic, to operate in harmony with the automatic brakes on the train and must provide for completely interlocked, independent operation of the locomotive and the train brakes.

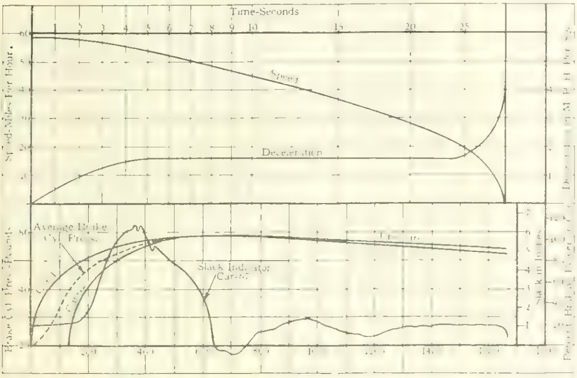


FIG. 29—EMERGENCY STOP CURVES, MODERATE RETARDATION

The combined automatic and straight air brake equipment furnished for interurban motor cars, running singly or in trains, is well adapted for the light locomotive service requirements, not only because it possesses the required functions, both on the automatic (for train service) and the independent (locomotive brake) sides, but especially because the same apparatus in all essential details is used on the locomotives as on the motor, passenger and express cars on the same line—an item of considerable importance in the handling of stores and repair shop tools and supplies, and where the operation and maintenance of all equipments is handled by the same force.

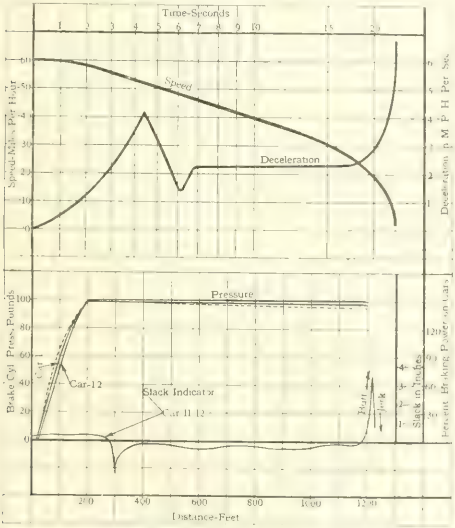


FIG. 30—EMERGENCY STOP CURVES, RAPID RETARDATION

The motorman controls the train and locomotive brakes together or the locomotive independently as he may choose, by a single brake valve. When running alone, the locomotive brakes (independent operation) are controlled directly by this brake valve, as with an ordinary straight air brake; except that the safety and effectiveness of the automatic brake are automatically available when needed. When in train service, the locomotive brakes can be operated alone by straight air, as just explained, or as if a part of and in conjunction with the automatic brakes of the train, according to the corresponding operating positions of the brake valve handle.

Heavy electric locomotive service, created by the substitution of the electric for the steam locomotive in trunk line, terminal, tunnel or heavy grade electrifications, demands the same operative features as provided by the displaced steam locomotive equipments, and in addition the special features required by the substitution of electric for steam motive force and the characteristics of the motor and control systems. Consequently, the brake equipment is fundamentally the same as is regularly used on steam locomotives, providing for the operations of the locomotive and the train brakes either independently or in conjunction; for the maintenance of brake cylinder pressure at the intended amount, regardless of either leakage or variations in piston travel, up to the capacity of the compressor; and

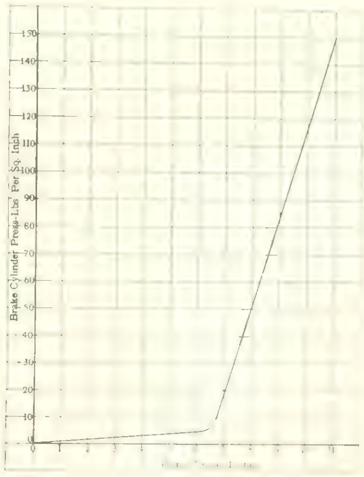


FIG. 31—EFFECT OF PISTON TRAVEL AND DEFLECTION IN BRAKE RIGGING ON BRAKE CYLINDER PRESSURE (IDEAL)

for 30 percent higher emergency cylinder pressure than the ordinary service maximum. The compressor is ordinarily motor driven and controlled by an electro-pneumatic compressor governor and switch device combined, if single unit service only is intended. It is arranged for the synchronous operation of all the compressors in double header or multiple-unit service.

On locomotives and motor cars where dynamotor, phase converter or other similar rotating units can provide sufficient excess power to drive the compressor and so do away with a separate motor drive, the opportunity to save expense and apparatus is always attractive. Several railroads are using such installations in regular service, with entire satisfaction. For such cases, some form of clutch or coupling is required and the governing mechanism must be either to bring the driving mechanism into or out of action or to unload the compressor. Each individual case of this kind has its own peculiar operating characteristics and requirements, respecting the form of drive, space limitations and governing mechanism, a study of which will determine whether the elimination of a separate motor driving the compressor will be justified or not.

The capacity of the locomotive brake, as ordinarily furnished for steam locomotive service, is inadequate for very long double-end locomotives or when it is desired to permit the engineer in the leading cab to control the brakes on both the first and second unit of a double header, independently of the train brakes. The increased capacity necessitated by larger volumes and longer piping connections is provided by additional devices which supplement but do not alter the operative features or essential devices of the standard locomotive equipment. Thus, the desired capacity and functional features are automatically made operative without requiring any additional knowledge or skill or any manipulation on the part of the engineer, other than for the familiar steam locomotive brake equipment. These are at once seen to be important considerations when the requirements of interchange, the class of labor, the demands of service upon the engineer's skill, alertness and judgment in other directions and the safety of property and life involved are taken into account.

With the electrification of important divisions of such railroads as the Norfolk and Western and the Chicago, Milwaukee and St. Paul for the handling of heavy tonnage trains on grades, the possibility of turning motors into generators when descending the grade has been utilized to serve the double purpose of generating current to supplement the power house delivery to the line, and by the resultant back torque on the motors, to control the speed of the trains down the grade without the wear and tear on brake shoes and wheels and the train slack control difficulties incident to heavy grade mechanical braking.

The characteristics of the electric locomotive motor and control equipment will determine whether the air brake can be used to supplement the regenerative resistance on the locomotive when the use of air brakes is desired, or whether regeneration will have to be cut out before the brakes are applied. When a considerable range of speed is available under regenerative control, there is ample margin for joint operation with the air brakes on the cars. But on the locomotive, with the motors already regenerating, the application of the air

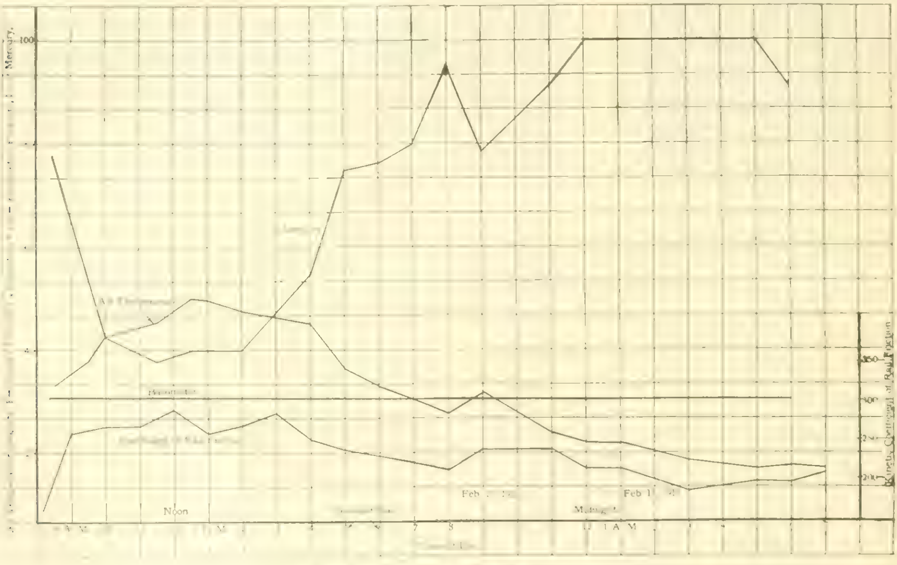


FIG. 3—[illegible] RAIL FRICTION

A 24-hour record of weather conditions and rail friction.

brakes to the driving wheels would be likely to increase their total resistance to rotation beyond the rail adhesion and cause sliding. To avoid this possibility, an automatic interlock mechanism is used, which permits the locomotive brakes to apply and release normally, so long as regenerative braking is not in effect, but the initiation of regeneration automatically releases the locomotive brakes, if applied, or prevents their being applied, so long as regeneration continues. This action in no wise affects the control of the brakes on the train as usual by the engineer. Furthermore, the interlocking devices are so arranged that, should the regenerative control be lost for any cause, the air brakes on the locomotive would automatically apply to a degree corresponding to the brake application then existing on the train or, if none did exist, the locomotive brake would be placed in readiness to respond, as in ordinary service, to any succeeding automatic or independent brake application. Provision may also be made for opening the main motor control circuits when an emergency application of the brake occurs.

The evident importance of these safety provisions helps to explain a phase of the combined regenerative and air brake control systems which is even more vital, but not always as fully appreciated. With a highly effective regenerative control available, the air brake might be thought to have become of less consequence. Indeed, it has even been suggested that with regenerative control it would be possible to handle heavier trains or the same trains at higher speeds than would be safe with the air brake on the same grade.

In such cases, however, it must always be remembered that the regenerative control is not an automatic safety device. It may become inoperative at a critical time and the air brake is then the only recourse for safety. But there is no safety if the train is beyond the capacity of the air brake. It would not be safe, therefore, even though it were possible, to control a train by regenerative resistance down grade at a speed in excess of the maximum safe speed for the air brake equipment.

The foregoing survey of the train control requirements of electric traction service merely mentions the distinctive characteristics of the various equipments used in the different classes of service enumerated. To describe in any detail the construction or operative features of individual devices would require a paper as long as this one on each of the several equipments referred to. The object of this article has been, rather, to show that the air brake is something more than a convenience—more even than merely a safety device—that it is, in fact, a most effective and efficient factor in that most critical and insistent problem of today, viz., the problem of transportation.

Switching and Protection of Transmission Circuits-IV

S. Q. HAYES

THE "Solid South" is rapidly being formed into a manufacturing district. Huge textile mills, steel mills and other factories are steadily increasing in number and size. This growth has been stimulated by and has helped to produce the many hydro-electric developments which have resulted in some of the most extensive networks of high-tension transmission lines in this country.

A typical example is the system of the Alabama Power Company, as shown in Fig. 59. The main transmission lines of this system form a triangle in the central part of the state with Lock 12 on the Coosa river, Bessemer near Birmingham and Jackson Shoals making the corners. From Bessemer, an arm extends in a northwesterly direction to the steam reserve station at Gorgas on the Warrior River and from that point to Sheffield where there is a 40 000 kv-a transforming station, used during the war for supplying power to the nitrate plant at Muscle Shoals.

From Jackson Shoals, lines extend in a general northerly direction through Anniston, Gadsden Station and Guntersville to Huntsville. Extensions are contemplated that will tie the line through Decatur to Florence, completing this upper ring. Tap lines have been projected that will tie this section of the system with the system of the Georgia Power Company at Lindale and at West Point.

From Lock 12 on the Coosa River, the southern section reaches down to Montgomery and at some future time other lines will be extended still farther south. Both 110 kv and 44 kv lines are in operation.

A single line diagram of the important transmission lines, Fig. 60, indicates the generators, transformers and transmission lines, with their reactances all figured out on the basis of 30 000 kv-a. The types of relays used at various points are indicated. As shown, the main hydroelectric generating station is located at Lock 12 on the Coosa River, the interior of this station being shown in Fig. 61. This plant has a dam approximately 1638 ft. long and 65 ft. high. The power house is 323 ft. long, 128 ft. wide and 160 ft. high, forming the shore end of the dam. There are four 17 500 hp and one 19 000 hp vertical-shaft water-wheels driving five 13 500 kv-a vertical shaft generators with five banks each of three 4500 kv-a, single-phase transformers, oil insulated and water cooled, stepping up from 6600 volts delta to 110 kv star, with arrangements for grounding the neutral through a resistance. A bank of transformers feeds the 44 kv line to Montgomery and the other banks operate in parallel on a sectioned 110 kv bus, from which two lines run to Jackson Shoals via Sylacauga and the other two to Bessemer.

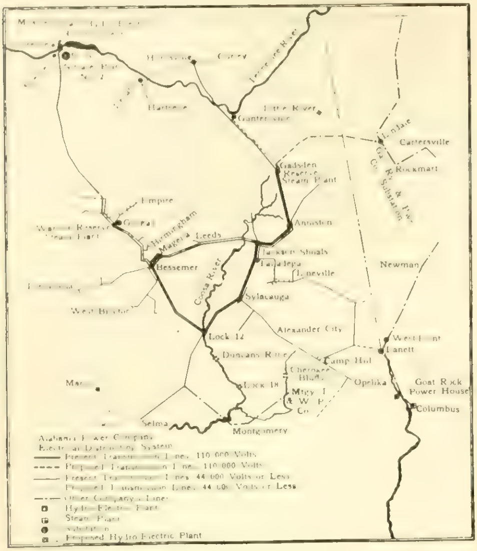


FIG. 59—HIGH TENSION TRANSMISSION SYSTEM OF THE ALABAMA POWER COMPANY

At Jackson Shoals on Choccolocco Creek there is a small hydroelectric plant, containing two vertical-shaft, double-runner turbines, each driving a 1000 kv-a, 2300 volt, three-phase, 60-cycle generator. At Jackson Shoals there is also located the outdoor switching and transforming station shown in Fig. 62. The bus-bars are hung overhead between strain insulators to the end cross girders, and supported by suspension insulators hung from the intermediate cross girders. This construction is facilitated by having the intermediate towers higher than the end ones. Cross connections are made by conductors stretched between strain insulators attached to the side longitudinal girders. The disconnecting switches are all of the inverted type, most of them supported by the framework located in the middle of the switch yard.

The circuit breakers in the 44 kv circuits are mounted on low platforms so that their live contacts will be out of reach of visitors. The disconnecting switches are hung at an angle from a triangular lattice girder above the breakers. The transformers are of the water-cooled type and get their circulating water from the elevated tank in the back ground. The choke coils in the outgoing line circuits are of the line suspension type, 15 inches in diameter, and make favorite nesting places for the small birds.

The other two outgoing lines from Lock 12 run to the Bessemer Angle switching station shown in Fig. 63. This view is taken from the point where two of the 110 kv lines tie unto the bus through the two oil circuit breakers in the right foreground, these being the lines shown on the diagram as connecting to the Magella substation. The next breaker to the left controls the bank of Westinghouse transformers tying together the 110 kv and 44 kv systems. Two 44 kv lines also run to Magella and one to the Tennessee Coal & Iron and Railway Co. plant at Ensley and from that point to Gorgas, the steam plant on the Warrior River. Two 110 kv lines also run direct to Warrior. The cooling pond for the circulating water of the transformers is shown in the foreground and the elevated water tank to the left.

In the background at the center is the switchboard house. The switchboard is provided with a complete miniature bus-bar layout, showing the main connections made by the various oil circuit breakers. Two panels control the motor-generator charging set and the storage battery for the operation of the oil circuit breakers.

From Bessemer Angle, as shown in Fig. 60, two 44 kv and two 110 kv lines go to the Magella substation in the suburbs of Birmingham. A 110 kv and a 44 kv tie line connect Magella with Jackson Shoals.

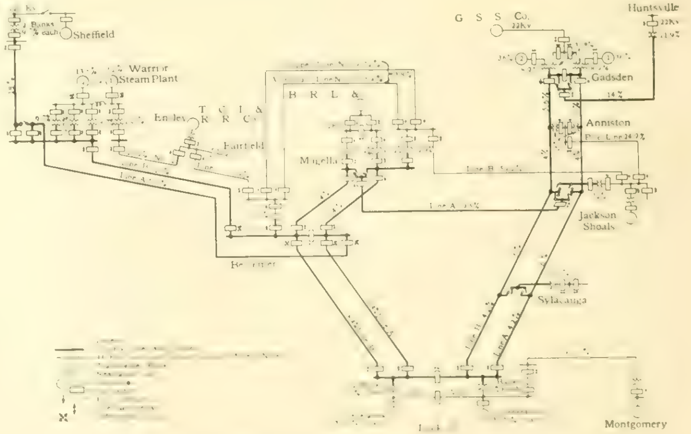


FIG. 60—SINGLE LINE DIAGRAM OF SWITCHING CONNECTIONS OF THE ALABAMA POWER COMPANY

Showing percent reactance of lines, transformers and generators based on 30 000 kv-a; also showing relay connections.

At the Magella substation near Birmingham, shown in Fig. 64, there are three banks each of three 4500 kv-a, single-phase, water-cooled transformers, two stepping down from 110 kv to 13.2 and one from 110 kv to 44 kv for transmission into Birmingham. Provision is made at various transforming and switching stations for tying together the 110 and 44 kv transmission circuits.

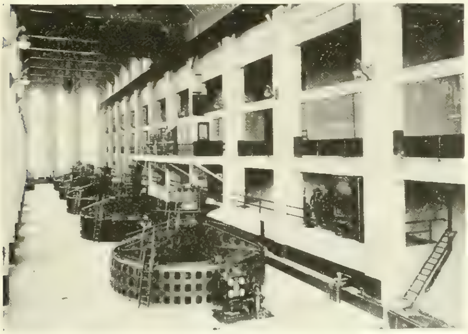


FIG. 61—INTERIOR VIEW OF GENERATING STATION AT LOCK 12

At Magella the cases of the transformers, oil circuit breakers and lightning arresters have been painted white, and as ample space has been allotted to the equipment, a very pleasing arrangement has resulted. The low-tension switching equipment, as well as the control switchboard, are located in a brick building in the background. The steel work for the support of the outdoor disconnecting switches, busbars, etc. is of light but rigid construction.

Fig. 64 shows the two transformer banks to the right of the control house and indicates the method of carrying the 44 kv leads over the structure by mounting them on pin type insulators attached to steel cross arms carried by vertical extensions of the supporting towers. It also shows the two different types of lightning arresters used with the 110 kv circuits. In both of these arresters the aluminum trays are arranged in two columns inside oval steel tanks and these columns are connected in series. In the nearest arrester, there is only one terminal per tank, the other terminal of the tray columns being connected to the tank and the tanks mounted on insulated platform. In the other arrester, each tank has two leads brought through the top, both terminals of the tray columns being insulated from the tank and the tanks grounded. Fig. 64 also shows the transformer bank to the left of the control house and indicates clearly the strain insulators for the 110 kv bus attached to the end girders, as well as the strain insulators fastened to the longitudinal side girders and used for the 110 kv cross connections. The high-tension leads from the transformers pass through the oil breakers and then through either set of disconnecting switches to either 110 kv bus. The 11 kv lightning arresters and the cooling pond are shown back of the control house.

Bessemer Angle switching station connects by two 110 kv and one 44 kv line to the Gorgas Steam station. This plant is located near a coal mine and in the heart of the Warrior River coal mining section of Alabama. It contains one 25 000 kv-a turbogenerator and one 33 000 kv-a turbogenerator and was used during the war to transmit power to the government Nitrate Plant at Muscle Shoals near Florence. At Gorgas the generator circuits, as well as the leads to the step up transformers are controlled by circuit breakers mounted in masonry compartments in the steam station, while the high-tension circuits are controlled by outdoor breakers. One bank of transformers supplies the 44 kv tie line through Ensley to Bessemer, and three 20 000 kv-a banks of transformers supply the 110 kv bus feeding the line to Sheffield and the tie to Bessemer Angle. The distance from Sheffield to Warrior is 90 miles; from Warrior to Coosa 75 miles; from Coosa to Gadsden 100 miles and other distances can be approximated from the map in Fig. 59.

At the Gadsden Reserve Steam Plant, there are two 7500 hp horizontal shaft steam turbines driving three-phase, 60 cycle, 2300 volt generators. Local steam plants are in service at Huntsville, Decatur and Guntersville in the northern part of the state, and at Marion in the west central part. These stations serve the immediately surrounding territory. The seven primary substations containing the important transformer banks and high-tension switching equipment are located at Warrior, Gadsden, Jackson Shoals, Magella, Anniston, Bessemer and Sylacauga.

Various hydroelectric plants are under contemplation, and provision will ultimately be made for a tie connection to the system of the Georgia Power Company at Lindale and at West Point. This system ties in with the Tennessee Power Company and Southern Power Company, allowing for an interchange of elec-

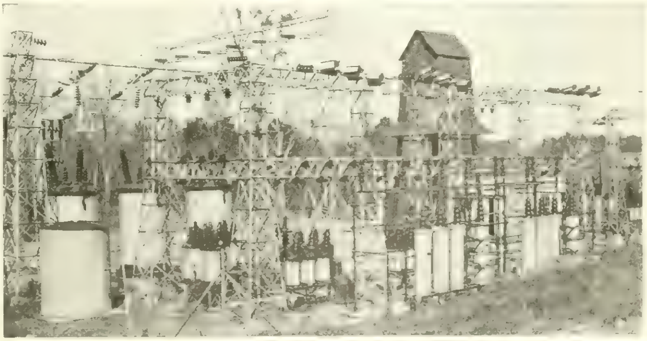


FIG. 62—JACKSON SHOALS SUBSTATION

trical energy through a large number of states in the South.

THE GEORGIA RAILWAY AND POWER COMPANY

The connecting links between the systems of the Southern Power Company in North and South Carolina, the Tennessee Power Company, and ultimately the Alabama Power Company, are formed by the system of the Georgia Railway & Power Company. The main generating station of this system is located at Tallullah Falls and contains five 10 000 kv-a vertical-shaft, 6600 volt turbogenerators each driven by a 17 000 hp, 514 r.p.m. waterwheel, with provision for a sixth unit.

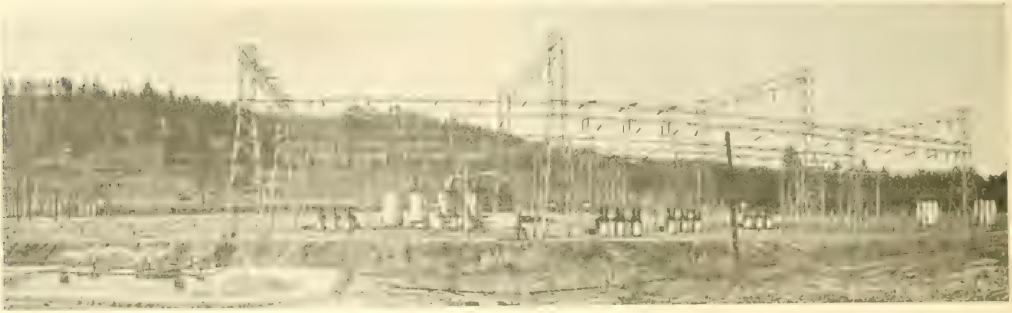


FIG. 63 BESSEMER ANGLE SUBSTATION

This plant is the highest head plant in the South. Each generator is provided with a direct-connected exciter, and three 3333 kv-a, single-phase transformers stepping up to 63 500 volts delta, 110 000 star with arrangements for grounding the neutral from the high-tension side of the transformers through a neutral resistor located at the end of the switch house. The generator rheostats are located under a gallery entirely isolated from the operating room, and ventilated by suitable louvres so that the heat can readily be carried away.

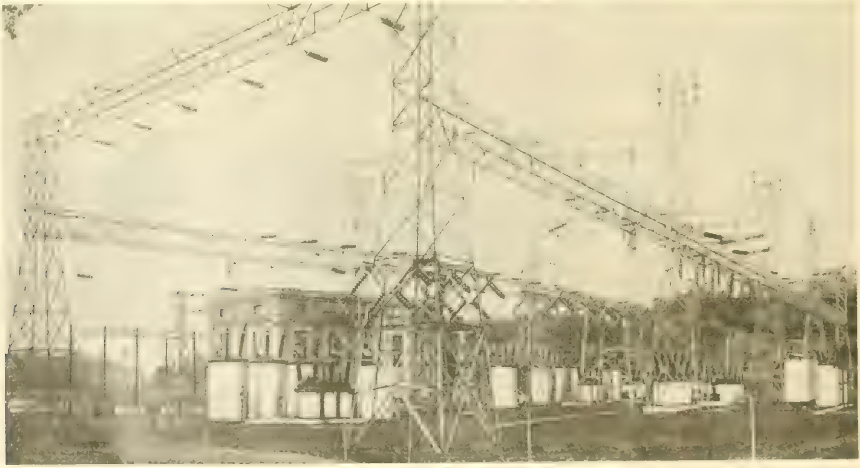


FIG. 64 MAGELLA SUBSTATION

In the main generating station, the entire excitation is taken from the direct-connected exciters, there being no motor generators or water driven exciters, but each of the direct connected exciters being capable of exciting two generators. While any generator can be connected to a low-tension transfer bus, it is normally operated with its own bank of step-up transformers, these being paralleled on the high-tension side.

As the power plant is located in a gorge, an indoor transformer and switch house has been provided immediately adjacent to the generating station, but higher up on the side of the gorge. The lightning arresters of the outdoor type are located still farther up the side of the hill.

Most of the power developed at Tallullah Falls is transmitted to Atlanta, but tie-in connections have been made so that the Tallullah Falls plant can furnish energy to the Southern Power Company, and the system of the Tennessee Power Company.

The most important substations on the system of the Georgia Railway & Power Company are located at Atlanta, Newnan, Marietta, Gainesville, Cartersville and Lindale, Georgia.

The Boulevard Substation in the outskirts of Atlanta, is the largest on the system, and was originally designed for three 10 000 kv-a transformer banks with an ultimate installation of six, each transformer bank comprising three 3333 kv-a water-cooled transformers, these being about the earliest water-cooled transformers built for outdoor service. The station is arranged for a total of six 110 000 volt lines, and 60 000 kv-a in transformers.

The high-tension wiring is divided into two sections, which are electrically joined together by a tie breaker. All of the high-tension wiring, the transformers and circuit breakers are located outdoors. The high-tension wiring consists of copper tubing bus-bars supported by hangers from a one-half inch copper clad messenger, this in turn being insulated from the steel framework by strain insulators.

Most of the power from the step-down transformers is transmitted into Atlanta, supplying energy to the street railways, lighting, power and other loads at that point. The system of the Georgia Railway & Power Company has other hydroelectric plants in different parts of the state with steam reserve stations in Atlanta. The Tugaloo development of the Georgia Railway & Power Company was held up due to war conditions, but is now being pushed through, and will add 12 345 kv-a to the available power on this system.

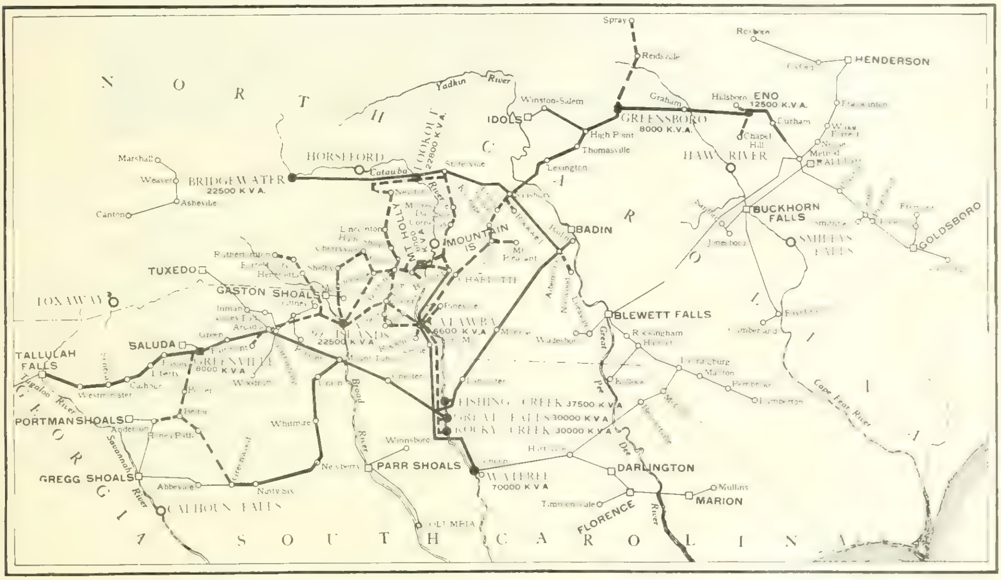


FIG. 65 HIGH TENSION TRANSMISSION SYSTEM OF THE SOUTHERN POWER COMPANY

Water power stations in service are solid circles, projected open circles. Steam stations in operation are solid squares. Southern Power Co. 100 kv. system are heavy lines, 44 kv. system broken lines. Other company systems are light lines.

THE SOUTHERN POWER COMPANY

The system of the Southern Power Company, as shown in Fig. 65, furnishes power for railway, lighting and industrial service over a large portion of North and South Carolina. Power is furnished to approximately one quarter of the total number of cotton spinning looms in the United States, as well as to about 1500 miles of interurban railway.

This system was formed in 1905, taking over at that time the 6600 kv-a plant at Catawba which had been built in 1904. The first new plant installed by the Southern Power Company was that at Great Falls, built in 1907, and containing eight 3750 kv-a waterwheel generators with transformers stepping up to 44 000 volts. This was followed by the plant at Rocky Creek, built in 1909, and also containing eight 3750 kv-a generators. The plant at Ninety-nine Islands built in 1910 contains six 3750 kv-a generators. These plants, with the reserve steam plants, took care of the service for several years.

In 1915 the Lookout Shoals plant of 22 500 kv-a capacity was installed, this being followed in 1916 by the plant at Fishing Creek with five 7500 kv-a units, that at Bridgewater in 1919 with two 12 500 kv-a units, and that at Wateree in 1919 with five 14 000 kv-a units.

There are three steam turbine reserve stations at Greenville, Greensboro, Mt. Holly, each with 8000 kv-a turbogenerators, and Eno with 12 500 kv-a turbogenerators. These turbogenerators are normally run as synchronous condensers to improve the powerfactor of the circuits. Connection is made at the Georgia and South

Carolina border with lines from the Tallullah Falls generating station of the Georgia Power Company.

Systems of the size of the Southern Power Company are growing rapidly. The latest available information on this system, gives a total generator capacity of 280 900 kv-a with 443 500 kv-a in transformers, and 250 miles of transmission line. Connections are made at Wateree and near Durham to the generating system of the Yadkin Power Company, and ties have been provided or are in contemplation with other power systems.

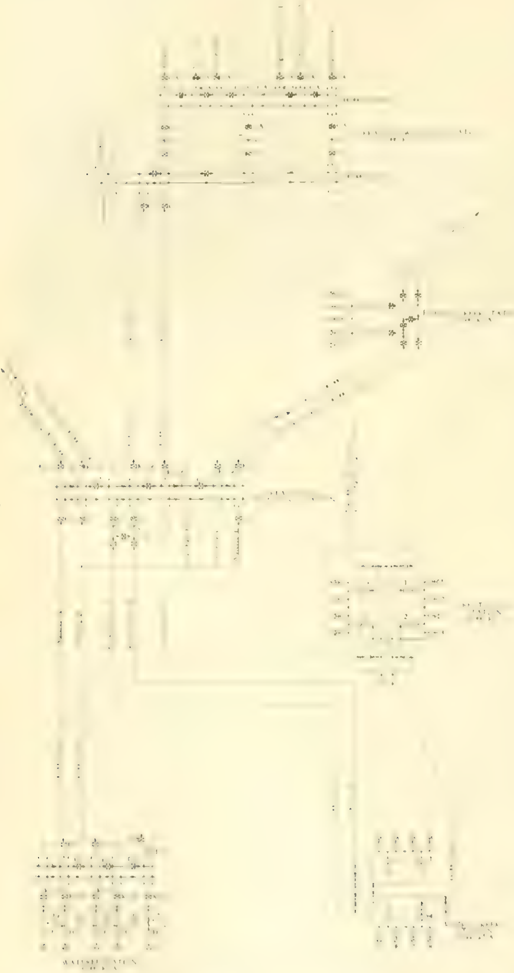


FIG. 66—SINGLE LINE DIAGRAM OF SWITCHING CONNECTIONS IN THE PRINCIPAL STATIONS OF THE SOUTHERN POWER COMPANY

Fig. 66 shows a single-line diagram of connections and indicates down to last July, the main connections furnishing energy to the Great Falls and Lakewood switching stations, as well as the supply circuits from the Great Falls Generating Station, Rocky Creek Generating station, Wateree and Fishing Creek stations. The balance of the generating stations are located on other parts of the system and are not indicated on this diagram.

At Rocky Creek and Great Falls the normal method of operation consists in connecting two 3750 kv-a generators to their own bank of three 2500 kv-a step-up transformers, these feeding through suitable breakers to a sectioned 44 000 volt bus. From the Rocky Creek station there are two 44 kv lines that run to the Great Falls Switching station and a 44 kv tie circuit going directly to the Great Falls generating station.

For the Wateree Plant each of the 14 000 kv-a generators is normally used with its own 14 000 kv-a step-up transformer, connecting through an outdoor oil circuit breaker, and double-throw disconnecting switches to either of two outdoor 100 kv busses.

The circuit breakers on the high-tension side of the transformers are those illustrated in Fig. 20 (May 1920, p. 186), these being the flat sided breakers, while those used for sectionalizing the busbars and in the 100 kv outgoing circuit to the Great Falls switching station are of the round tank design, shown in Fig. 23.

From the Great Falls station, 44 kv circuits are run to the Rocky Creek station, to Charlotte and to other points, with provision made for direct circuits to the Great Falls switching station. At the Fishing Creek station the normal method of operation contemplates employing two 7500 kv-a generators feeding into one 15 000 kv-a transformer bank, there being two banks at this point, and generator, No. 3 being normally held as a reserve. From this point two 100 kv circuits are run to Salisbury and two circuits go to the Great Falls switching station. At the Great Falls switching station the main power of the system is concentrated. At this point there are two incoming lines from Wateree, two from Rocky Creek, two from Fishing Creek with provision made for additional circuits to the Great Falls station and to the Wateree station. The circuits from Rocky Creek pass through transformers stepping up from 44 to 100 kv.

At Great Falls the circuit breakers in the incoming circuits from Wateree, and the circuit from the high-tension side of the step-up transformers fed from Rocky Creek are of the round tank type as are the breakers used for sectionalizing the high-tension bus. The breakers in the incoming lines from Fishing Creek and the two outgoing lines to Lakewood and the two outgoing lines to Spartanburg, are of the flat tank type.

At the Lakewood Station there are two incoming circuits from the Great Falls switching station and provision is made for 100 kv outgoing lines to Salisbury and Gastonia. At Lakewood three banks are at present installed, each of three 4000 kv-a transformers stepping down from 100 to 44 kv. Each transformer bank is provided with an oil circuit breaker on the high-tension side, of the type shown in Fig. 19 with oval tanks, these same circuit breakers being used on the incoming line from Great Falls and its bus sectionalizing circuit breakers.

On the 44 kv circuits, each transformer bank is provided with a circuit breaker and double-throw disconnecting switches, so that it can be connected either to a main bus, sectionalized by breakers, or to a transfer bus, sectionalized by disconnecting switches. Outgoing circuits to Hoskins, Mt. Holly, Gatesville, Highland Park and Water Works are each provided with oil breakers and double-throw disconnecting switches.

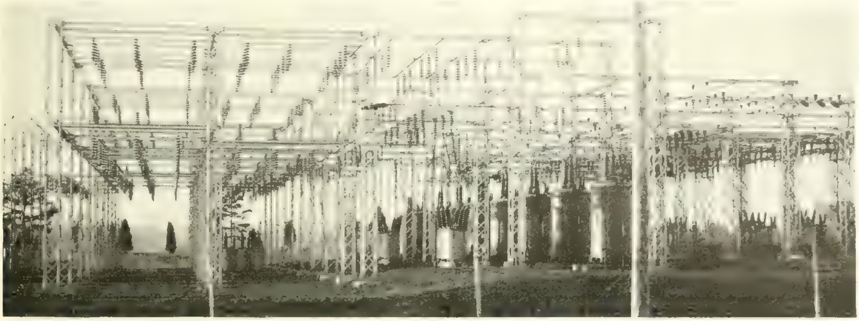


FIG. 67 LAKEWOOD SUBSTATION

The general arrangement of the Lakewood switching station is given in Fig. 67, illustrating the type of steel framework, bus-supports, disconnecting switches, circuit breakers, transformers and similar equipment used at that point, the 100 kv circuits being shown to the left and the 44 kv to the right. Each oil circuit breaker tank, arrester tank, and transformer tank is placed on a small concrete foundation. The transformers are so arranged that they can readily be rolled onto a truck running on a track, so that they can be removed for inspection or repair.

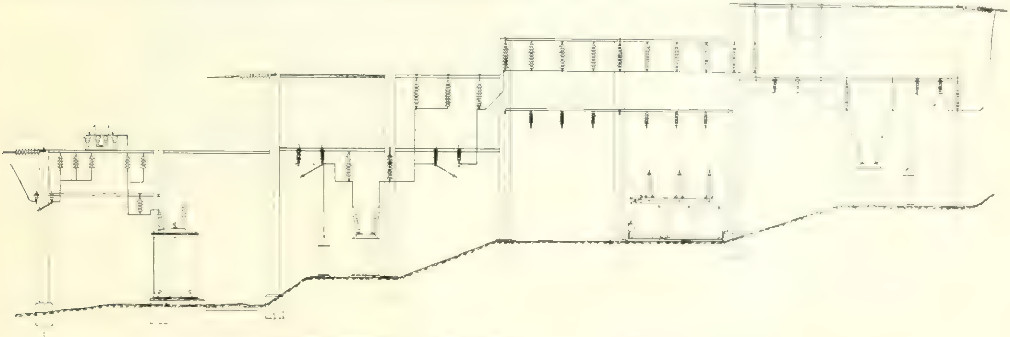


FIG. 68 SECTIONAL DIAGRAM OF GREAT FALLS SWITCHING STATION

Fig. 68 shows a sectional view through the Great Falls switching station, and gives an idea of the relative location of the circuit breakers, disconnecting switches, bus-bars, transformers, and other equipment. The transformers shown at the left hand end of this figure are the transformers stepping up from 44 to 100 kv in the Rocky Creek circuit. These transformers are on wheels, so that they can be readily rolled onto a truck and transported to the repair shop, if this should ever prove necessary. This drawing does not show the 100 kv connections running from the transformers, but these are taken through the disconnecting switches, current transformers, and circuit breakers. The high-tension connections from these transformer breakers are taken through disconnecting switches to the main or transfer bus in the manner shown on the single line diagram. The transfer bus is sectionalized by disconnecting switches and the main bus by the round tank circuit breakers. The outgoing 100 kv line circuits are controlled by the circuit breakers, and the outgoing circuits pass from these circuit breakers through current transformers and disconnecting switches to the high-tension line circuits.

The Southern Power Company was one of the pioneers in the development of outdoor switching and transformer installations, and has done a great deal of pioneer work in connection with power transmission in the supplying of energy to cotton mills over large distances. As it is impossible to illustrate or describe all of the power plants on a system of this magnitude, attention will be confined to the latest hydraulic plant, that of Wateree.

The interior of the Wateree plant is shown in Fig. 69. This plant contains five 14 000 kv-a vertical-shaft, water-wheel generators with direct-connected exciters.

The generators are set back far enough from the wall to leave ample space inside the power house for running in through suitable doors the step-up transformers that are located immediately outside the building on a concrete platform overlooking the tail race, as shown in Fig. 70. These transformers are the 14 000 kv-a, three-phase, water-cooled units illustrated in Fig. 13. The power house forms the shore end of the dam with the step-up transformers located immediately outside of the building so as to reduce to a minimum the length of the low-tension leads.

The high-tension leads from these transformers are run diagonally to the switch yard on the bank at the power house end of the dam on the down stream side. These transformer leads are approximately 300 ft. long and are supported by strain insulators attached to the power house building and similar insulators attached to the steel work of the transformer yard.

One very interesting feature of this switch yard is that it consists of a concrete platform set up on concrete pillars at such a height as to be beyond the flood level. A general view of this switch yard is shown in Fig. 22. The outgoing transmission lines from Wateree to the Great Falls switching station are carried across the river on towers.

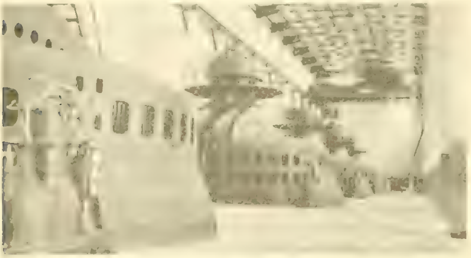


FIG. 69—INTERIOR VIEW OF WATEREE GENERATING STATION

THE TENNESSEE POWER COMPANY

The Tennessee Power Company, that connects with the Georgia Power Company's line may be considered as one of the groups of large systems in the southeastern part of the United States. This system had an original installation of approximately 15 000 kw, with an ultimate capacity of 75 000 kw, transmitting power over two lines at 120 kv from Cleveland to Nashville, Tennessee a distance of 140 miles.

Station No. 2 contains two 10 000 hp horizontal-shaft waterwheels operating under a head of 250 feet, driving two 9375 kv-a generators, with 9375 kv-a three-phase transformers connected delta-delta, stepping up to 120 000 volts, one furnishing energy to the Parkesville north line, the other to the Parkesville south line.

The plant at Halesbar, originally the property of the Chattanooga and Tennessee River Power Company, contains a number of 3133 kv-a vertical-shaft, 6600 volt, three-phase, 60-cycle generators with transformers stepping up to 44 kv, and supplying energy to the Halesbar Chattanooga North line, and the Halesbar Chattanooga South line. Three 10 000 kv-a, three-phase transformers and one 12 000 kv-a three-phase transformer step the voltage up to 120 000 for the Halesbar College Junction line. These Tennessee systems tie in with the plant of the Aluminum Company of America, whose Marysville No. 1 plant receives power at 110 kv from the Tennessee Power Company. At this plant there are fifteen 3500 kv-a, single-phase transformers stepping down from 110 kv to the voltage needed for nineteen 2500 kw, six-phase rotary-converters. The transformers are arranged in delta-connected banks with one spare on the high-tension side of each transformer and four independent secondaries so arranged that a bank of three 3500 kv-a transformers will supply the current for four six-phase converters, using the diemetral system of connections.

The Aluminum Company of America has a hydro-electric plant on the Little Tennessee River, containing four 20 000 kv-a vertical-shaft waterwheel generators, the energy from this plant being transmitted to the Marysville No. 2 station, where three 14 000 kv-a single-phase outdoor transformers reduce the voltage to 13 200, these in turn feeding other outdoor transformers supplying power to fourteen 2500 kw rotary-converters. The Marysville No. 3 plant receives power at 140 kv, stepping it down by outdoor transformers and supplying current at 13 200 volts, to twenty 5000 kw converters. Various water-power plants, aggregating about 300 000 kv-a are under consideration for supplying energy to various rotary-converter stations.

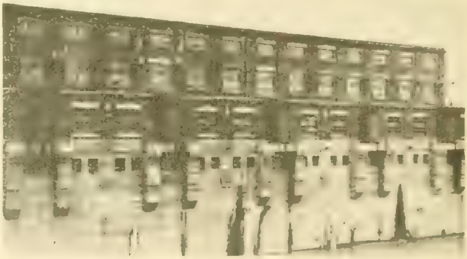


FIG. 70—EXTERIOR VIEW OF WATEREE GENERATING STATION
Showing location of outdoor transformers.

The Parkesville No. 1 generating station contains five 3750 kw, 2300 volt, three-phase, 60-cycle, horizontal-shaft generators driven by 5400 hp waterwheels at 360 r.p.m., and there are four 3750 kv-a. O. I. W. C. three-phase transformers stepping up from 2300 to 66 000 volts, power being transmitted to Cleveland, a distance of 13 miles from the power house. At the Cleveland switching station a line approximately 26 miles long runs to Chattanooga, another line approximately 85 miles northeast to Knoxville, and a line 70 miles south to Rome, Ga.

The New Portable Oscillograph

As Applied to Commercial Work

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The portable oscillograph recently constructed in the experimental department of the Westinghouse Electric & Mfg. Company, has proved itself to be exceptionally flexible in its adaptibility to extremes of service conditions. A description of this oscillograph was presented in the *A. I. E. E. Journal* for July 1920. Emphasis of certain features and a description of recent commercial applications are given in the following article.

THE method of analyzing electrical problems by oscillograms is growing rapidly in importance with the natural growth in size and number of inter-connected power systems. This makes it highly desirable that what has hitherto been considered as primarily a laboratory instrument, difficult to move, and requiring considerable time to set up in a new location, should be so modified as to be readily portable. Not only has this been accomplished without any sacrifice in precision of measurement or reliability, but additional features have been incorporated which make the new oscillograph simpler to manipulate and give it a much wider range of application than its predecessors.

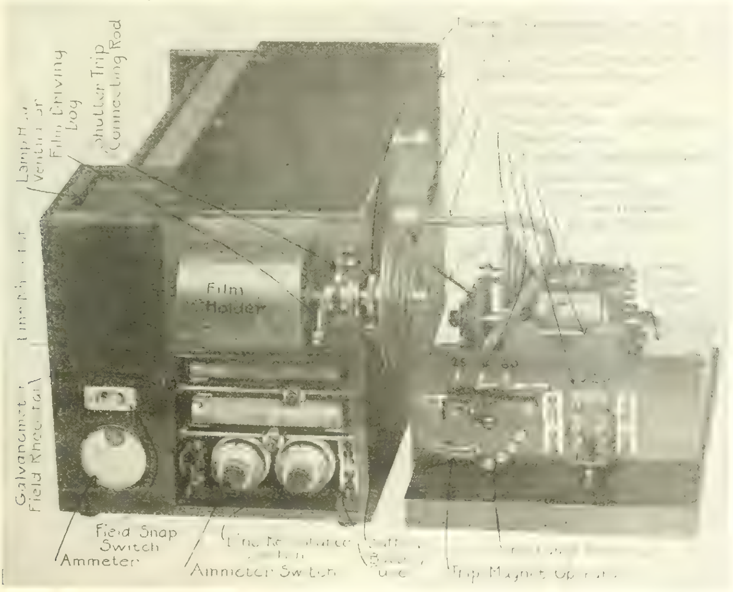

FIG. 1—FRONT VIEW OF OSCILLOGRAPH CONNECTED TO OPERATING MECH[illegible]

The new oscillograph is complete in two units, as shown in Fig. 1. The main case is 14 inches high, 13 inches wide and 25 inches long, overall. The housing for the incandescent lamp is shown at the extreme left. The photographic drum and driving head are attached to the optical box. Beneath are the control switches and the ammeter for indicating the field current of the galvanometer. The motor board is separate and carries the induction motor, fitted with step grooved pulleys and back gears; the transformer; the lamp control rheostat; the double-pole double-throw switch for 110 or 220 volt transformer operation; the single-pole, double-throw switch for connecting the motor to 55 volts for low-frequency or 110 volts for high frequency operation; and the protecting fuses.

The series electromagnet galvanometer only 7 by 7 by 4.25 inches, over all, is shown in Fig. 2. By the use of four insulating gaps and three effective (element) gaps in series in the magnetic field circuit, each of the three elements is insulated for over 10 000 volts from its neighbor, and still the flux between the pole tips is sufficiently strong, with but 10 watts applied to a single exciting coil.

GALVANOMETER VIBRATOR

The vibrator element, Fig. 3, has a very rugged construction. The frame is turned from a single piece. One binding post is grounded to the frame while the other is connected to one solder terminal which, with its insulating bushing, passes through the frame at a slant. The fine vibrating ribbon is soldered to this terminal and passes through one set of slots in the two ivory bridges, thence around the tiny ivory pulley, back over the bridges in the other set of slots, and is soldered to a grounded terminal. The ivory pulley is on a balanced lever the other end of which receives the proper tension from an adjustable spring, located in a recess in the rear of the frame. The tiny mirror is cemented across the vibrating ribbons half way between the bridges. The parallel ribbons are within a hair's breadth of one another. When in the galvanometer they are located in a strong magnetic field, so that when the current passes down one and up the other, they twist the mirror in proportion to the current. The element top completely closes the damping fluid well, so that the oil need not to be removed during transportation.

The panel, which gives control of the element circuits, can be seen in Fig. 4. There are two dials to control the resistances for the element. The resistances are wound on thin micarta cards, so as to be nearly non-inductive, and are located beneath the galvanometer compartment. The upper dial ranges from 0 to 100 ohms while the lower (larger) dial ranges from 100 to 10 000 ohms. As the element takes about 0.12 ampere per inch deflection on the photographic drum, it is seen that one lower dial is sufficient to give proper element deflection for peaks as high as 4000 volts direct-current, of 1500 volts alternating-current. The upper resistance dial should be used for e.m.f.'s below ten volts, or for regulating the deflection of an element when across a current shunt. By the use of a double set of binding posts, together with a double-pole, double-throw switch, the element may be switched quickly from a voltage recording position to a current recording position, without changing connections.

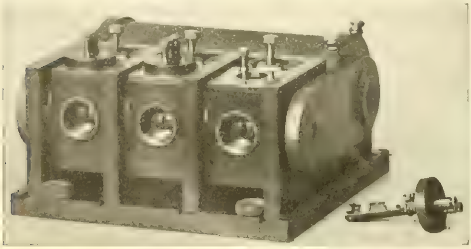
FIG. 2—THREE ELEMENT GALVANOMETER WITH SERIES MAGNETIC CIRCUIT

The side of the optical box is shown in Fig. 5, with the driving head and the film drum attached. The novel features are:—the focal plane drum shutter and mechanical shutter release; the trip magnet and remote control switch; and the lamp extinguishing switch. The double conductor, passing to the driving head, is in the trip magnet circuit. An adjustable contact, on the driving head, closes this circuit any desired fraction of a revolution ahead of the opening of the shutter. This should be set to equal slightly less than the time which will be required for the remote control apparatus to function. As is the case with several other makes, this oscillograph records the instantaneous values of three currents or voltages accurately to a fraction of a thousandth of a second. The length of the exposure depends on the speed of the photographic drum. With this apparatus the drum speed may be varied from about twelve hundred to sixty revolutions per minute, giving an exposure of from 0.05 second to 10 seconds.

For fast films the incandescent lamp is placed, momentarily, on a 60 percent excess voltage, which, if continued, would cause the lamp to burn out in less than one second. Either a filament for a very heavy current (18 amperes or more) or a specially constructed ribbon filament is used. With the automatic lamp control of this oscillograph, thousands of films may be taken before burning out the lamp. For slow films, which have been taken up to three-quarters of an hour exposure, the lamp needs but slight abnormal voltage.

EXAMPLE OF OPERATION

The operation of this oscillograph can best be understood by giving an example of the various operations in their proper sequence. The oscillogram shown in Fig. 6, is a record of the magnetic blowout action of a railway switch or circuit breaker. The lower curve (left hand element) is a record of the building up of the current through an inductive reactance, then the cutting off of the current by the rupture of the arc formed across the separating contacts by the magnetic blowout action of the switch. The element, in series with its low-resistance dial, was placed across a non-inductive shunt to obtain the instantaneous current. The center element was placed in series with its high-resistance dial across the jaws of the circuit breaker, and thus gave a record of the instantaneous voltage of the arc. The third element was used for a timing wave, to determine the true speed of the film for that particular belt position. A belt position was chosen which would give the photographic drum one revolution in somewhat greater time than it would take for the current to build up and break. This timing wave, from the 25 cycle, 110 volt motor transformer supply, shows that the film had a speed of 9.3 inches in five cycles. Thus, for this particular belt position and 25 cycle

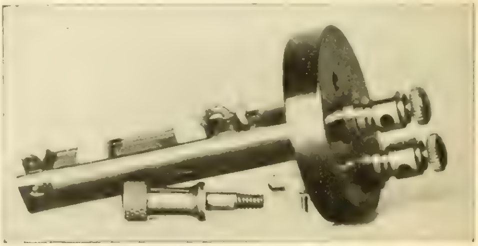
FIG. 3—GALVANOMETER VIBRATOR ELEMENT

supply to the driving motor, one inch on the film represents $(5 \div (25 \times 9.30) =)$ 0.0215 second. Any number of films may be taken at this speed with no more than 0.2 percent variation in speed, assuming the frequency constant. As the time taken for the switch to close, after excitation of the remote-controlled operating magnet, was about 0.1 second, the contact, on the oscillograph driving head was set for about 4.75 inches lead of the film, ahead of the position on the film where the operator desired the current record to start. The breaker was set to trip after the full-load current value was passed.

For Any Test:—The transformer switch was placed in the down position for 110 volt operation. The motor switch was turned to the left for 25 cycle operation, thus revolving the film at the predetermined speed. The galvanometer field switch was closed (the ammeter indicating the proper field strength). Then the lamp control rheostat was turned to the abnormal voltage position against the trip magnet stop. As the contact on the driving head short-circuited the brushes in the trip-magnet circuit, the latter released the remote control switch, which closed the operating magnet circuit in the railway switch. Before the switch became fully closed, the shorter shutter finger was dropped by the shutter release crosshead; the focal plane drum shutter was thus snapped open (at the overlapping of the film) and the longer finger held the shutter open. During the first half of the exposure the crosshead made an inward stroke, which shortened the radial length of the second finger. As the crosshead receded, a spring caught and held the second finger at the same radial length as the first finger, hence the second finger was dropped by the crosshead and the shutter closed, one revolution after the first finger, thus giving just one revolution exposure to the photographic drum. A radial arm on the shutter shaft struck against the lamp extinguishing switch (located between the trip magnet and the case) as the shutter snapped closed, thus opening the lamp circuit and preventing the destruction of the filament by the over-voltage applied.

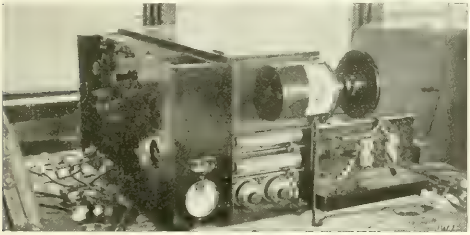

FIG. 4—OSCILLOGRAPH SET UP FOR TEST ON A MULTIPLE-UNIT CAR

During this exposure the switch actually closed; the current built up in the inductive circuit; the switch jaws opened; the arc established across the jaws was blown out by reaction of a series magnetic field; the sudden decrease in current caused a high-voltage kick across the jaws from the stored energy of the inductance; this high voltage caused a re-establishment of the arc across the electrodes accompanied by a decrease in arc voltage; other re-establishments followed; when the stored energy of the inductance was nearly dissipated, the arc was at last blown out successfully. All of this occurred in a very short space of time. The record of the rupture of the arc extended over 2.3 inches of the film, which represents 0.05 second. The current built up for 0.12 second before rupture started. This particular switch was rated at 200 amperes, while this test was made at 1000 amperes with a huge reactance.

COMMERCIAL DESIGN INFLUENCED BY OSCILLOGRAPHIC STUDY

An example of the great value of the oscillograph is shown by comparing the two oscillograms, Fig. 6 and Fig. 7. The two films were taken at the same speed and same sensitivity of elements, hence they can be directly compared. The latter shows the action of an old switch of the same rating, put to the same test. After an oscillograph and high speed camera study, a new switch was developed which ruptures even a greater current in one third the time. Furthermore, the voltage characteristic of the new switch is predominantly high, (as is also shown by high speed camera pictures*) showing that the arc keeps out on the horns, while the voltage characteristic of the old switch is predominantly low showing that the arc tends to hang in near the contacts, thus unduly pitting them and shortening their life. Notice, however, that the peak voltages are about the same for the two switches. The initial and final line e.m.f., is seen to be 600 volts. As could be foretold from the oscillograms, the life of the new switch proved to be many times that of the old form, and its successful ultimate rupturing capacity was several times greater.

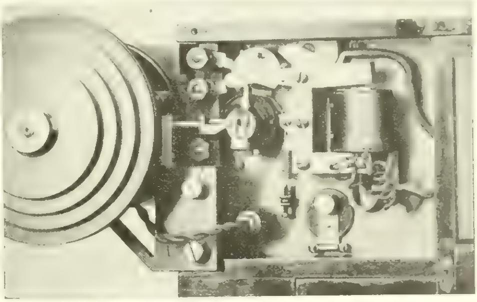

FIG. 5—SHUTTER TRIP AND REMOTE CONTROL MECHANISM

With the special automatic control of the incandescent lamp and shutter it has been possible to take and develop nearly a hundred oscillograph films in one day, for no re-adjustment of the oscillograph is needed when it is once set up for a particular test. Oscillograms have been made at the rate of more than one a minute, when little or no adjustment was required on the circuit being tested. Several hundred oscillograms have been made without changing a single adjustment on the oscillograph.

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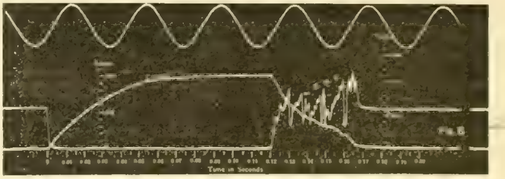
*Described by the author in the JOURNAL for Dec., 1919

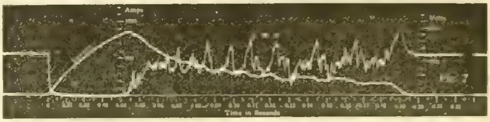
TESTS MADE ON ELECTRIC CARS

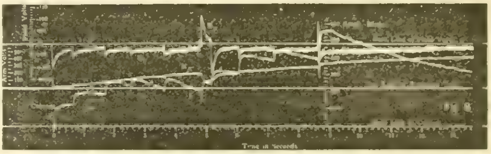
An example of the extreme portability, flexibility, and reliability of the new oscillograph was shown in the tests made on cars of the United Railways & Electric Company of Baltimore. Tests were made on one car. Then the apparatus was transferred to a multiple-unit control car, and arranged so that over two dozen combinations of voltage and current could be obtained from various parts of the motor and switch circuits. The oscillograph incandescent lamp was operated from a 12 volt lighting battery borrowed from an automobile. A toy motor, running from the storage battery, was used to drive the film drum. Over forty films were taken in one day, nearly all of them with the car in motion. None of these films were developed until after the apparatus was all taken away, yet but one film of the whole lot was spoiled, and that because it accidently fell in the fixing bath before it was placed in the developer. All of these films were of transients which were automatically started within an inch or two of the beginning of the film. They gave instantaneous records of current and voltage for various operations, such as:—change from one controller notch to another; change from series to parallel operation of motors; application of an excessive current which operated the overload trip; reversal of the motors with power; braking by bucking one motor against the other; acceleration at normal and at abnormal speeds; interruption of line voltage; etc. Fig. 4 shows the portable oscillograph set up during these tests in Baltimore. This apparatus is more complete than most oscillographs which are mounted on two trucks, an oscillograph truck and a storage battery truck.

A good oscillogram, from an engineer's standpoint, is one with the finest lines possible which will still be clear in the original print. With such fine lines the current and voltage curves may be scaled accurately. On the other hand, the curves must be heavy to show well in publications, but such curves are not as desirable for extreme accuracy. Hence an oscillogram cannot be judged from a cut in a publication as the best oscillograms will need to be touched up or traced.

Fig. 8 is a record of fast acceleration of a multiple-unit car. The curve with its zero line at the bottom is that of total motor current. The central zero line is for armature voltage, E_A. The upper zero line is for series field voltage (deflection down) E_F. The scale of time is shown at the bottom of the oscillogram with the start of current taken as zero. The oscillogram shows the building up of current and voltage as the controller passes through the nine notches. Transition from series-parallel to parallel motors occurs 2.5 seconds after start. The ninth notch is reached at 4.3 seconds. The record continues to the seventh second. The current on the first notch shows the building up effect of inductance, but on the later notches it shows a decline, after the initial kick, due to the increasing back e.m.f., of the armatures produced by acceleration. The armature voltage shows the initial inductive kick and an increasing drop due to the acceleration. At transition the armature voltage drops momentarily and the field voltage momentarily reverses. The field voltage is mainly inductive. The fine oscillations are due to the brushes passing over commutator segments. The maximum current, on the ninth notch, is seen to be 560 amperes. This dies down to 310 amperes at the end of the exposure (6.9 second) with an armature e.m.f. of 425 volts and a field e.m.f. of 20 volts.







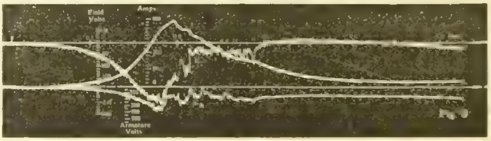


FIG. 6—RAILWAY SWITCH TESTS

25 cycle timing wave. 1000 amperes, 600 volts, 17 millihenries. $R = E \div I = 600 \div 1000 = 0.6$ ohms. When $I = 632$, $t = 0.0282$ sec. $L = tR = 0.0169$ henry. $I = \frac{E}{R}\left(1 - \epsilon^{-\frac{Rt}{L}}\right)$. $I_t = 0.632 \times I_M$ at $t = L/R$ for $\epsilon = 2.718$.

FIG. 7—RAILWAY SWITCH TEST

1000 amperes, 600 volts, 17 millihenries, 0.6 ohms.

FIG. 8—OSCILLOGRAM OF FAST ACCELERATION OF TYPE HL MULTIPLE-UNIT CONTROL GEAR WITH FOUR MOTORS

FIG. 9—OSCILLOGRAM OF BRAKING BY THE LOOP METHOD

No power from trolley. Controller on first notch reverse.

Fig. 9, is a record of braking by the loop method. Three-tenths second before the start of the exposure the oscillograph remote control switch started the electro-pneumatic operation of the reverser, which connected the motors so that the residual field of one caused that one to build up as a generator and force current through the other as a motor, both of which tend to bring the car wheels to a stand-still. The film shows the building up of the current to 380 amperes and the dying away of the current as the car wheels slip. This was followed, a moment later, by a second building up and a second slipping of the wheels, etc., until the car came very nearly to a stop. The field voltage and armature voltage curves are also shown. At time 0.18 second the wheels began to slip, as shown by the kick in the current. At time 0.195 second a sputter, under the brush, caused a more rapid decrease of current and a kick in the field voltage wave. In the original print the fine oscillations in the field voltage wave can be counted to determine the instantaneous rate at which the commutator segments passed under the brush. From this the instantaneous speed of the car can be determined. The extreme jolting of the car had no effect on the accuracy of the oscillograph record.

This oscillogram also brings out the great ease with which zero lines can be located. The exposure always begins just slightly before the overlapping part of the film, hence on the outstretched film the initial deflection is shown at both ends. Usually the initial deflection is zero for at least one element, when transients are being taken. Consequently straight inked lines can be drawn as zero lines with the extremes of the film as gauge points.

MULTIPLE OPERATION OF OSCILLOGRAPHS

For moderate speed films (of one-half second exposure or over) any number of portable oscillographs can be operated simultaneously and still be located in different stations and record the different local effects of the same transient started by the remote control switch of one of the oscillographs. The closing of one switch, which supplies the motors and lamps of the several oscillographs, would cause the motors to bring each photographic drum up to speed, in about 0.1 second, and also bring the lamps up to abnormal brilliancy and start the remote control apparatus so as to bring the transient on the film at the desired place. By reconnecting the lamp-extinguishing switch, it can be made to break the motor circuit, as well, and thus the photographic drums will make but two revolutions each, one revolution being the effective exposure, and the other for starting and stopping. In cases where there is a possibility of high voltage danger this alternating-current supply switch can be operated at a safe distance by pulling a string.

The making of nine simultaneous records on three films, using three oscillographs, was made very simply by the special devices on the portable oscillograph. Hundreds of films were taken, in this way, of oil switch tests at 13 200 volts with three-phase currents up to 27 000 amperes. The pulling of a single string closed the motor and lamp circuit of the portable oscillographs. One motor drove the three photographic drums, the three lamps were placed in series across the abnormal voltage. The 13 200 volt closing switch was actuated from the oscillograph remote control switch, the films were exposed simultaneously and the closing of the drum shutter tripped the little circuit breaker in the motor and lamp circuit, thus preventing the destruction of the lamps. Out of the first seventy-five films there were but three failures, which were due to damaged film holders, and not to any novel feature of the portable oscillograph. The special features of this oscillograph probably saved the company which built it an amount equal to the cost of the apparatus, in two months time.

Switchboard Meter Connections for Alternating-Current Circuits-X

Synchronizing with a Synchronoscope

J. C. GROUP

THE inductor type synchronoscope, an instrument similar in general appearance to other switchboard meters and more accurate and dependable than lamps, is most commonly used as a synchronism indicator. There are other forms of synchronoscopes, but only the inductor type, such as shown schematically in Fig. 99, will be considered. The instrument has two windings, one shown at the upper part of the case for connecting to the incoming machine, and the other at the lower part for connecting to the running machine. The running winding consists of two parts, one of which is connected in series with a non-inductive resistance and the other with an inductive resistance in order to produce a rotating field necessary for the operating elements. The pointer can rotate freely in either direction, and is so arranged that when the frequency of the incoming machine is lower than that of the running machine it rotates in the direction indicated by SLOW on the dial, or if the frequency of the incoming machine is higher than that of the running machine it will rotate in the opposite direction, indicated by FAST on the dial. When the frequencies of both machines are the same, the pointer will stop at some position around the dial, depending on the angle by which the voltage of the incoming machine is out of phase. The instrument is so designed that when the two machines are in synchronism the pointer will be in a vertical position pointing upward, and that position is the only one marked on the dial. Thus the instrument indicates when the frequencies of the two machines are the same and also when they are exactly in synchronism.

Connections for synchronizing between any generator and bus are shown in Fig. 100. The synchronizing switches are the same as in Fig. 97.* In order to synchronize any generator, the key is inserted in the synchronizing switch of that generator and the switch is moved to the ON position. Then, beginning with the voltage transformer connected to the generator, the side of the secondary in which the fuse is shown, is connected through points *3* and *2* of the synchronizing switch to the incoming synchronizing bus *I*, and from this bus through the incoming winding of the synchronoscope to the ground wire which completes the circuit to the other side of the secondary of the voltage transformer. The corresponding side of the secondary of the voltage transformer connected to the bus, in which the fuse is shown, is connected to the synchronizing bus *B*, from this bus through points *4* and *5* of the synchronizing switch to the running synchronizing bus *R*, and from this bus through the running winding of the synchronoscope to the ground wire which completes the circuit to the other side of the secondary of the voltage transformer. When thus connected, the synchronoscope indicates when the incoming generator is in phase with the bus. The small arrows show the directions that the voltages must take through the windings at the same time so that the instrument will indicate synchronism.

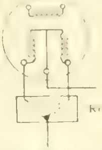


FIG. 99—SYNCHRONOSCOPE CONNECTIONS

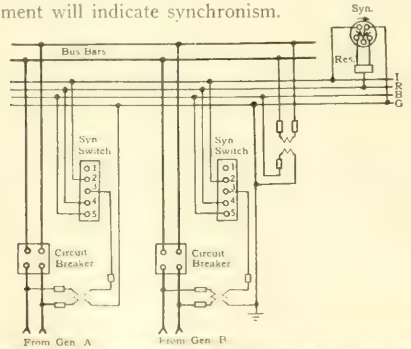


FIG. 100—SYNCHRONIZING BETWEEN ANY GENERATOR AND BUS

The connections in Fig. 101, are for synchronizing between any two generators. The synchronizing switches are the same as shown in Fig. 98, two keys being necessary. If it is assumed that generator *A* is running and that generator *B* is to be synchronized with *A*, first the running key is inserted in the synchronizing switch on the switchboard panel controlling generator *A* and the switch is moved to the RUNNING position, and then the incoming key is inserted in the synchronizing switch, on the panel controlling generator *B*, to move that switch to the INCOMING position. Tracing through the synchronizing circuits, beginning with the voltage transformer connected to generator *A*, the side of the secondary in which the fuse is shown is connected through points *2* and *3* of the synchronizing switch, to the running synchronizing bus *R*, and from this bus through the running winding of the synchronoscope to the ground wire which completes the circuit to the other side of the secondary of the voltage transformer. At the same time the corresponding side of the secondary of the voltage transformer connected to generator *B*, in which the fuse is shown, is connected through points *2* and *1* of the synchronizing switch to the incoming synchronizing bus *I*, and from this bus through the incoming winding of the synchronoscope to the ground wire which completes the circuit to the other side of the secondary of the voltage transformer.

Lamps are used in addition to a synchronoscope in a large majority of switchboard installations for the purpose of providing a second means for observing the phase relation of the voltage of the incoming machines. It is the usual practice to mount a synchronoscope on a swinging bracket or small swinging panel at one end of a switchboard, preferably at the left hand end when facing the front of the board, so that the instrument may be readily seen by the operator from any position along the entire length of the switchboard. The most convenient location for the lamps is on the bracket or panel near the synchronoscope so that while the operator is watching the synchronoscope the lamps can also be observed without any special effort. Connections for an arrangement of this kind, for synchronizing between any generator and bus, are shown in Fig. 102. The synchronizing switches and the connections are the same as in Fig. 100 except that lamps are connected between the incoming and running synchronizing busses. The synchronizing circuits can be more easily understood from the schematic diagram in Fig. 103, which shows how the incoming winding of the synchronoscope is connected across the secondary of the generator voltage transformer and the running winding is connected across the secondary of the bus voltage transformer. The lamps and the secondaries of both voltage trans-

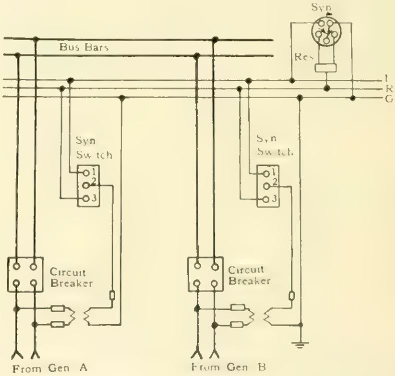


FIG. 101—SYNCHRONIZING BETWEEN ANY TWO GENERATORS

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*In the JOURNAL for Nov. 20, p. 537.

formers are connected in series, forming a circuit similar to that explained for Fig. 97, except that here the same two lamps are used for any generator, being connected in by the synchronizing switches along with the synchronoscope.

Connections for synchronizing between any two generators with a synchronoscope and lamps arranged the same as in Fig. 102 are shown in Fig. 105. The synchronizing switches and the connections are the same as in Fig. 101 except that the lamps are connected between the incoming and running synchronizing busses. A schematic diagram of the synchronizing connections for the condition where generator *A* is running and generator *B* is to be synchronized is shown in Fig. 104. This diagram is almost the same as Fig. 103 and is self explanatory.

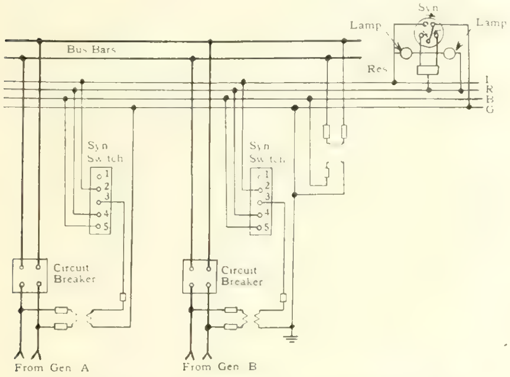

FIG. 102—SYNCHRONIZING BETWEEN ANY GENERATOR AND BUS
With synchronoscope and lamps.

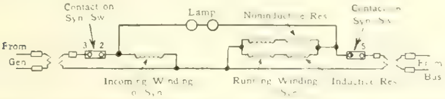

FIG. 103—SCHEMATIC DIAGRAM OF CIRCUITS SHOWN IN FIG. 102

In another method of synchronizing between any generator and bus, a lamp is located on each switchboard panel controlling a generator. This method, however, is seldom used, because it is not convenient for an operator to observe a lamp on the switchboard panel and watch the synchronoscope which is located somewhere else (usually at the end of the switchboard). Connections for this method are shown in Fig. 106. The synchronizing switches and the connections for the lamps are the same as in Fig. 97, and the synchronoscope is connected the same as in Fig. 100.

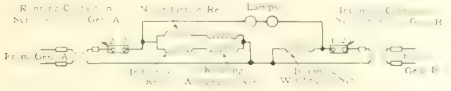

FIG. 104—SCHEMATIC DIAGRAM OF CIRCUITS SHOWN IN FIG. 105

Where the circuit breakers are electrically operated, synchronizing switches are sometimes provided with an interlock contact that makes it necessary for the synchronizing switch to be moved to the incoming position before the circuit breaker can be closed from the control switch on the switchboard. In Fig. 107, connections are shown with this arrangement for synchronizing between any generator and bus. The synchronizing switches are similar to those in Fig. 97, except that, as shown by the development, there is an additional contact which closes between points *6* and *7* for the electrical interlock. The synchronizing connections are the same as in Fig. 102, the lamps being located at the synchronoscope. The circuit breakers are operated by a standard four-wire control from a control switch which is equivalent to a single-pole, double-throw knife switch. The development shows the connections made for the three positions, all points being open for the OFF position, points + and *C* being connected together for the CLOSE position, and points + and *T* being connected together for the TRIP position. The indicating lamps are connected so that the red lamp burns when the breaker is closed and the green lamp when the breaker is open. The closing circuit from point *C* on each control switch is taken through the interlock contact (points *6* and *7*) on the synchronizing switch so that the circuit breaker will not close when the control switch is thrown to the CLOSE position un-

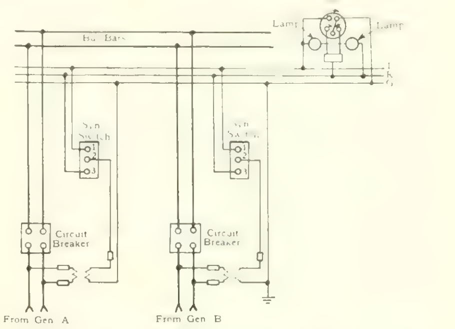

FIG. 105—SYNCHRONIZING BETWEEN ANY TWO GENERATORS
With synchronoscope and lamps.

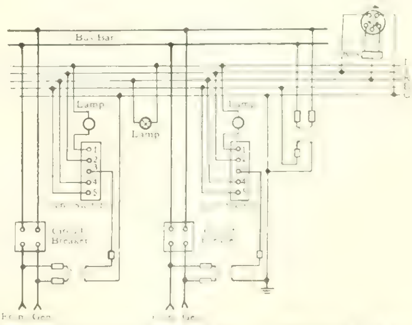

FIG. 106—SYNCHRONIZING BETWEEN ANY GENERATOR AND BUS
With synchronoscope and with lamps located on the switchboard panels.

less the synchronizing switch has first been moved to the ON position. This insures that the synchronoscope must be operating on the incoming circuit before the circuit breaker connecting in that particular circuit can be closed.

In Fig. 108, connections are shown for an arrangement, similar to that in Fig. 107, for synchronizing between any two generators. As shown by the development the synchronizing switches have three positions for operating with two keys, the same as those in Fig. 98, except that an additional contact is made between points *4* and *5*, in the incoming position, for the electrical interlock. The circuits formed when synchronizing are the same as in Fig. 104.

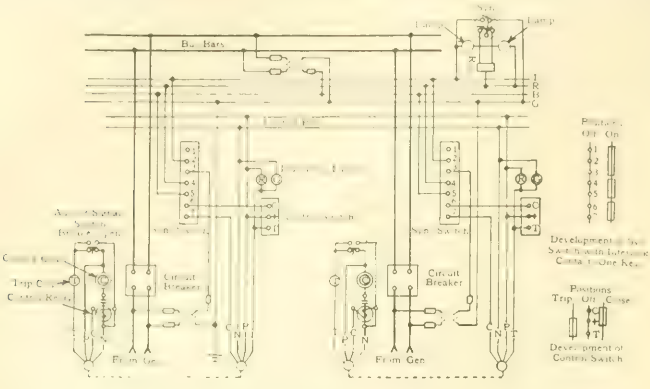

FIG. 107—SYNCHRONIZING BETWEEN ANY GENERATOR AND BUS
With synchronizing switches interlocked with electrically-operated circuit breakers.

Three-phase voltages are commonly stepped up to a high value for transmission lines through transformer banks which are connected in delta on the low-tension side and star on the high-tension side as shown in Fig. 109. Special connections are necessary for synchronizing around such a transformer bank, because the line voltages on the high-tension side are shifted 30 degrees from the corresponding line voltages on the low-tension side. The same kind of a synchronizing switch and arrangement of synchronoscope and lamps are used as shown in Fig. 102, but the arrangement of voltage transformers and connections to the synchronizing switch are different. The phase relation of the voltages may be explained in connection with the vector diagram in Fig. 110. Voltage vectors $E_{1\,2}$, $E_{2\,3}$ and $E_{3\,1}$, 120 degrees apart, represent the low-tension line voltages and also the phase voltages in the delta-connected winding of the transformer bank. $E_{0\,1}$, $E_{0\,2}$ and $E_{0\,3}$ represent the corresponding phase voltages in the high-tension star-connected winding of the transformer bank, or the voltages from the neutral point to each high-tension line respectively. The high-tension line voltage $HE_{1\,2}$ from line *1* to line *2* is equal to $E_{0\,1}$ — $E_{0\,2}$ (vectorially) and is 30 degrees ahead of the low-tension line voltage $E_{1\,2}$. Likewise $HE_{2\,3}$ and $HE_{3\,1}$, 30 degrees ahead of $E_{2\,3}$ and $E_{3\,1}$ respectively, represent the high-tension line voltages from line *2* to *3* and *3* to *1*. The high-tension line voltage $HE_{2\,3}$ is used for synchronizing, the voltage transformer being connected between lines *2* and *3* on the high-tension bus. E_1 represents the voltage on the secondary side of the high-tension bus transformer, and is the voltage connected to the incoming winding of the synchronoscope through the synchronizing switch. In order to produce a voltage from the low-tension bus in phase with E_1, two voltage transformers are used, one having a middle tap on the secondary winding. The voltage transformer with the middle tap is connected between lines *1* and *2* and the standard transformer between lines *2* and *3*. On the vector diagram the vectors $E_{1\,2}$ and $E_{2\,3}$ may be used also to represent the voltages on the secondary side of the voltage transformers and therefore $\frac{1}{2}\,E_{1\,2}$ represents the voltage between the middle tap and an outside lead on the secondary of the special transformer. The voltage E_R, equal to $E_{2\,3} + \frac{1}{2}\,E_{1\,2}$ (vectorially), is 30 degrees ahead of $E_{2\,3}$ and is in phase with E_1. The voltage E_R is connected to the running winding of the synchronoscope through the synchronizing switch. The synchronoscope thus connected indicates when the voltages are in phase for the two sources to be connected together through the transformer bank.

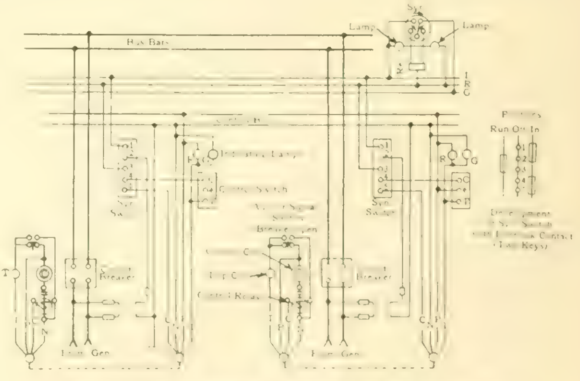

FIG. 108—SYNCHRONIZING BETWEEN ANY TWO GENERATORS
With synchronizing switches interlocked with electrically-operated circuit breakers.

In this case, the voltage E_R produced for the running winding of the synchronoscope is only 86.6 percent of the voltage on the secondary side of the voltage transformers. Should the voltage of the low-tension bus be the same as the nominal primary voltage of the voltage transformer connected to that bus, so that there would be 100 volts on the secondary side, E_R would be only 86.6 volts, which is too low, for usually a synchronoscope will not operate satisfactorily under 90 volts. For such a case the voltage transformers should have nominal 115 volt secondaries, so that 100 volts would be available for the synchronoscope. Then if it is desired to operate other meters from these transformers, the special transformer should be provided with 100 volts taps in addition to a middle tap. However, if the voltage of the low-tension bus be greater than the nominal primary voltage of the voltage transformer so there would be 100 volts or more on the secondary side, at least 95 volts would be available for the synchronoscope and that would be sufficient. In Fig. 109 the voltage from the low-tension bus is used for the running side of the synchronoscope and that from the high-tension bus for the incoming side, but the synchronoscope would operate just as well if the voltage from high-tension bus were used for the running side, for usually such a transmission line connects between bus-bars of two stations in each of which are generating machinery. With the arrangement shown in Fig. 109, either the high-tension or the low-tension circuit breaker may be used for connecting the two sources of power together when in synchronism.

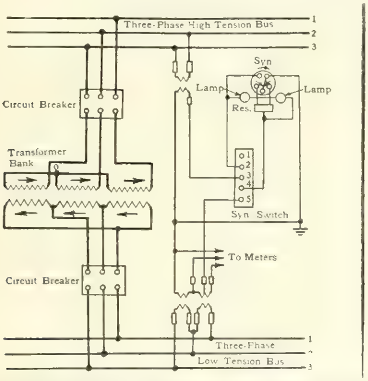

FIG. 109—SYNCHRONIZING AROUND A DELTA-STAR CONNECTED TRANSFORMER BANK

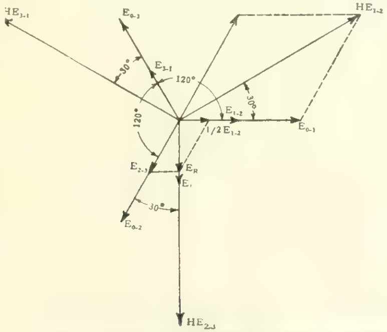

FIG. 110—VECTOR DIAGRAM OF VOLTAGES IN A DELTA-STAR TRANSFORMER BANK

Synchronizing around a delta-star connected transformer bank may be accomplished with the connections shown in Fig. 111. If the neutral point on the high-tension side is accessible, one side of the voltage transformer may be connected to it. The high-tension voltage transformer is shown connected to the phase voltage from the neutral point to line *2* and the corresponding voltage on the secondary side is connected to the incoming winding of the synchronoscope through the synchronizing switch. The low-tension line voltage from line *2* to line *3* is in phase with the high-tension phase voltage, from the neutral point to line *2*. Therefore, the low-tension voltage transformer is connected to the voltage from line *2* to line *3* and the corresponding voltage on the secondary side is connected to the running winding of the synchronoscope through the synchronizing switch. The phase voltage on the high-tension side of the transformer bank is equal to the high-tension line voltage divided by $\sqrt{3}$ and a high-tension voltage transformer should be provided with such a ratio that the secondary voltage will be about 110. With the arrangement shown in Fig. 111, the high-tension circuit breaker must always be closed first, in order to energize the high-tension voltage transformer for operating the synchronoscope, and the two sources of power are connected together, when in synchronism, by the low-tension circuit breaker.

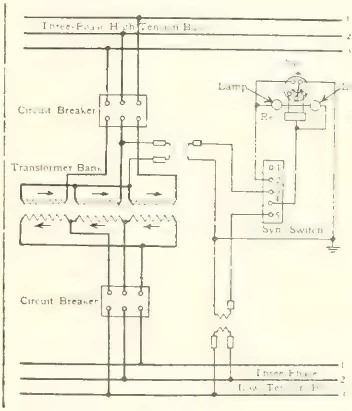

FIG. 111—ANOTHER SCHEME FOR SYNCHRONIZING AROUND A DELTA-STAR TRANSFORMER BANK

Effect of Voltage Variations on the Characteristics of Direct-Current Motors

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Motor Engineering Dept.,
Westinghouse Electric & Mfg. Company

DIRECT-CURRENT industrial motors in this country are usually built for either 115, 230, or 550 volts. The user is often concerned with a question as to how a given motor, that he either has, or can readily procure, will act on some voltage different from that at which it was rated. Either he may wish to use this motor on a line of another voltage, as using a 230 volt motor on a 220 volt or a 250 volt line, or he may desire to use the motor on a line where the voltage fluctuates greatly.

In approaching this question it should be kept in mind that speed will vary with the voltage. Before any further analysis can be made, there should be some assumption as to how the horse-power required of the motor will vary with the speed. This will change with the various motor applications. For simplicity, in the following discussion the horse-power output of the motor is assumed to be constant at all speeds. Having determined what the characteristics would be at this given horse-power on another voltage than rated, and knowing the effects produced on its characteristics by simply changing the load, it is easy to estimate what the result of voltage change would be, if the application was such that a change of speed caused a change of load.

For example, suppose a motor, connected to a blower runs at 1000 r.p.m. with line voltage of 230 volts, and requiring ten horse-power at that speed, is put on a 260 volt line. Assume that the speed does not vary appreciably with load when the voltage is constant, but that the load varies as the cube of the speed. Also assume that increasing the voltage to 260 increases the speed to 1100 r.p.m. This article indicates the characteristics of the motor when delivering 10 hp at 260 volts, 1100 r.p.m. Actually however the horse-power required is $(1100/1000)^3 \times 10$ or 13.3 hp. Once knowing how the motor will act at 10 hp, 260 volts, it is simply a question of the effect of loading to tell what it will do at 13.3 hp.

In the same way in estimating what a motor for any given application will do at any other voltage than rated, the first step is to estimate what the motor will do at its rated horse-power on the new voltage, and the second is to estimate the difference caused by the load under the new conditions.

EFFECT OF VOLTAGE VARIATION ON SPEED

For a given motor, the speed is proportional to the volts induced and inversely proportional to the flux per pole. The induced voltage is equal to the line voltage minus the *IR* drop in the motor. It varies nearly with the line voltage, particularly in large and high-speed motors. The flux will vary in different degrees with the field ampere-turns. One extreme is when working on the straight line of the saturation curve. Here the flux would vary directly with the field ampere-turns. The other limit would be when the machine becomes so saturated that a change in field ampere-turns does not change the flux. The actual case is always some place between these two limits. Fig. 1 shows a typical no load saturation curve. The full-load curve falls a little below the no-load curve, the distance depending on the load. This change of flux with load of course effects the speed variation due to voltage variation, but so little that it will not be considered. The saturation curve will be considered fixed regardless of load amperes.

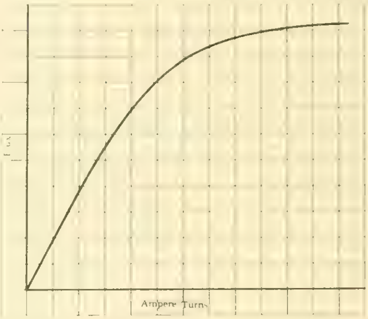

FIG. 1 TYPICAL NO-LOAD SATURATION CURVE OF DIRECT-CURRENT MOTOR

Then, for an entirely unsaturated motor, the flux varies with the ampere-turns and line voltage, and the speed will remain practically constant with voltage change. With a saturated motor, the flux would remain constant even though the field ampere-turns did vary with voltage, and as a result the speed would vary approximately with the voltage, a ten percent increase of voltage giving practically a ten percent increase of speed. These are the two limits. Commercial machines are worked at various places between these limits. In estimating on a shunt motor of unknown design characteristics, the speed variation can be estimated approximately on the basis that a ten percent increase of voltage will give five percent increase of speed.

Assuming constant efficiency, the current will vary inversely with the voltage. Then it is seen that for a series motor, the field ampere-turns vary inversely with the line voltage. The two limits of flux variation and speed variation with voltage would then be:—first, when working on the straight part of the curve the flux would be inversely proportional to the voltage and the speed would vary approximately as the square of the voltage; second, when saturated, the flux would be constant regardless of voltage and the speed would vary about with the voltage. The part of the curve worked on varies in a series motor with the load. Therefore either of these extremes may be nearly reached at different loads on a given series motor.

The characteristics of the change of no-load speed with the voltage on a compound-wound motor is the same as for a shunt motor, as then the shunt field is the only one with any appreciable ampere-turns. At full load, however, both shunt and series coils are effective, and the variation of speed with voltage change is some place between that of a shunt motor and that of a series motor. If the series coil predominates, the speed will vary more nearly like that of a series motor. If the shunt coil is the stronger, the speed will vary more nearly as does that of the shunt motor. In the normal compound-wound motor, the shunt field is usually much stronger than the series field and will cause the motor to work well up on the saturation curve. In such a motor the total field ampere-turns will vary but little with change of voltage, for while the shunt field strengthens with increase of line voltage the series field will weaken. Also, as such a machine is usually fairly well saturated, it is probable that, for small changes of voltage, the speed will vary proportionately with line voltage, a ten percent increase of voltage giving a speed increase of about ten percent. This of course, changes with the design and loading of the particular motor considered.

On compound-wound motors, the no-load speed and full-load speed vary in a somewhat different way, and the net result of this difference is that an increase of voltage rapidly decreases the speed regulation; that is, the percentage speed drops from no-load to full-load while a decrease of voltage rapidly increases it.

EFFECT ON LOSSES

The losses in a motor are affected differently by a change of line voltage. Armature copper loss, and losses in the series coils, the commutating field, and compensating (pole face) coils vary with their resistance and the square of the current flowing through them. Resistance can be considered constant. As before, the current should be taken as inversely proportional to the voltage. Then roughly, these losses vary inversely with the square of the voltage. In the same way, taking its resistance as a constant, the shunt coil loss will vary with the shunt current squared times the resistance. In this case then, the current is proportional to the voltage and the shunt coil loss is proportional to the square of the voltage.

The brush contact drop loss is not very important and follows peculiar laws. The voltage drop will remain practically constant and, assuming it constant and multiplying by the current, it is found that the brush contact drop loss is nearly inversely proportional to the voltage.

The friction and windage loss depends on the speed, it increases as the speed increases. It usually is only a minor loss, but on high-speed machines becomes important. It would be impossible to make a general approximation of the increase of this loss with the increase of voltage. The friction and windage losses, however, vary more rapidly than the speed.

The degree in which iron loss varies with voltage in different machines changes very much with the design, and it would be rash to venture an estimate as to the percentage change of iron loss with a given percentage change of voltage. The laws of iron loss indicate that it varies with some power of the speed, the power being some place between the first and second, and with some power of the maximum flux density in the armature iron; this power being between 1.6 and 2. The powers mentioned would vary with the design. It is safe to assume that the armature iron loss will increase when the voltage impressed is increased. It probably, in any given case, will increase faster than the voltage.

EFFECT ON EFFICIENCY

A summation of the losses shows that an increase in the line voltage will cause an increase in the losses that are largely independent of the load; as shunt loss, friction and windage loss, and iron loss. At the same time the losses depending on the load decrease. This includes losses in the armature copper, the commutating coils, the series coils, the compensating windings and the brush contacts. The sum of the total change of losses is probably very small for most motors. In case it becomes zero, since the output is taken as constant, the efficiency would remain unchanged. In a machine where the losses independent of the load are high, as compared to those dependent on load, an increase of voltage probably would decrease the efficiency while, if this ratio is low, the increase of voltage probably would increase the efficiency. In arriving at all general conclusions in this article, the efficiency is taken as constant, which makes the current from the line inversely proportional to the line voltage. On present-day open motors the efficiency would usually be very little affected by a 10 percent change of voltage from rated.

EFFECT ON HEATING

As with losses, a change of voltage affects the various parts of machines differently. The change of speed would either help or hurt ventilation. The effect of this on temperatures, however, will be so small for the probable change of voltages that it can be neglected. Assuming this constant, the tendency then is for all parts that have their losses increased to run hotter, and all that have their losses decreased to run cooler. Then with an increase in voltage the armature may or may not run cooler, depending on whether the reduction in copper loss more than makes up for the increase of iron loss or not. This would vary with the design of different motors. The shunt coil would tend to run hotter, and the series, commutating and compensation coil would tend to run cooler. A reduction of voltage would give the opposite effect in each case. So far as heating is concerned, then, the heating of the shunt coil will set the limit to the increase of voltage, and probably the heating of the commutating coils will set the limit to voltage decrease. In some motors this might, however, be set by armature heating.

As stated, the tendency is for the shunt coil temperature to increase and the commutating coil temperature to decrease with increase of voltage. This action is greatly modified by the fact that the temperatures of each of these coils is dependent not only on the losses in the coil itself, but also on the temperature of the air cooling it and on the temperature of the adjacent parts. Consequently, when the losses in part of the field coils increase at the same time as those in another part decrease, the change of temperature in each part is less than the change of losses in that part would indicate. On a machine of unknown design, a fair estimate probably would be that a ten percent increase of voltage on a motor carrying rated load would increase its shunt coil temperature rise five to ten percent while a ten percent decrease in voltage would give about a fifteen percent increase of commutating coil rise.

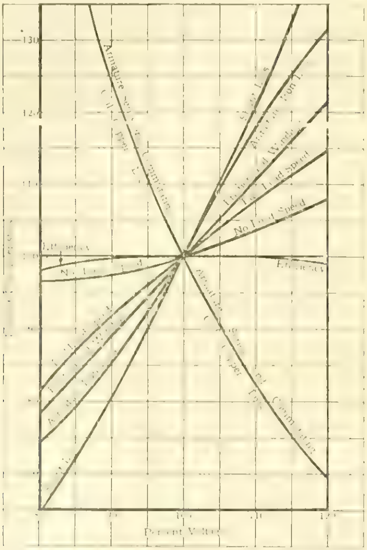

FIG. 2—VARIATION OF THE CHARACTERISTICS OF A COMPOUND WOUND MOTOR WITH CHANGE IN VOLTAGE

EFFECT ON COMMUTATION AND FLASHING

The present day commutating-pole motors have usually very good commutating characteristics. The motor should be expected to operate over a wide range of voltage before any serious sparking is caused. The motors most likely to be an exception to this are short-time rated motors.

Flashing tendency is increased by an increase of voltage, but this is a trouble that normally is never encountered, and should not be encountered on moderate voltage changes, except possibly on short-time rated motors of high voltage. In ordinary continuous rated commutating-pole motors of 115 and 230 volts, no trouble should be encountered from commutation or flashing even when run at as much as twenty percent under or over voltage. Of course exceptions may be encountered at times.

In the noncommutating-pole motor, a possible result of changing voltage would be a necessity of shifting the brushes, as the armature current would change, giving much the same results as regards brush position as would a corresponding change of load.

A concrete demonstration is given in Fig. 2 and Table I of the effect of changing the line voltage on the full-load speed, on the losses, and on the efficiency of a direct-current motor, assuming the output to be constant. The motor whose design is assumed and so analyzed is a 10 hp, 1150 r.p.m., compound wound, commutating-pole motor. The shunt coil at normal rating has about three times as many ampere-turns as the series coil. This should be fairly representative of most industrial sizes of direct-current motors now in use.

TABLE I—CHANGE OF CHARACTERISTICS OF A DIRECT-CURRENT MOTOR WITH CHANGE OF IMPRESSED VOLTAGE, HORSE-POWER KEPT CONSTANT

Horsepower	10	10	10	10	10
Percent normal voltage	80	90	100	110	120
Speed—No load	1300	1315	1350	1305	1450
Speed—Full load	935	1050	1150	1240	1320
Shunt field loss	92	117	144	174	207
Series field loss	78	60	48	39	23
Comm. field loss	92	70	56	46	39
Arm. copper loss	680	522	416	342	287
Brush loss	66	84	75	68	62
Arm. iron loss	250	300	352	415	462
Total friction and windage	158	183	205	220	247
Efficiency	83.5	84.8	85.2	85.2	84.7

It should be evident from the foregoing that the only way that maximum permissible voltages variation can be given to cover all motors or even a line of motors is either to have them all designed exactly the same, getting the same ratio between armature copper loss, and armature iron loss, all temperature rises the same, and all working at the same place on the saturation curve, or else to give the limit of such a value that all machines will meet it in every way. In this latter case then practically all will stand a bigger variation than the limit indicates. Since it is impossible to design and build an absolutely uniform line of motors, the second method is the one used. The Electric Power Club rules, specify that "all motors shall operate successfully at normal rated load at any voltage not more than ten percent above or below the name plate rating, but not necessarily in accordance with the standards of performance established for operation at normal rating." Manufacturers usually give a guarantee that conforms to these rules.

Electrical Characteristics of Transmission Circuits-XIV

Heating Limits for Cables

WM. NESBIT

THE MAXIMUM safe-limiting temperatures in degrees C at the surface of conductors in cables is given in the Standardization Rules of the A. I. E. E. (1918) as follows:—

For impregnated paper insulation (85—E)
For varnished cambric (75—E)
For rubber insulation (60—0.25 E)

Where E represents the effective operating e.m.f. in kilovolts between conductors and the numerals represent temperature in degrees C. Thus, at a working pressure of 5 kv, the maximum safe limiting temperature at the surface of the conductors in a cable would be:—

For impregnated paper insulation (80 degrees C)
For varnished cambric insulation (70 degrees C)
For rubber compound insulation (58.75 degrees C)

The actual maximum safe continuous current load for any given cable is determined primarily by the temperature of the surrounding medium and the rate of radiation. This current value is greater with direct than with alternating current and decreases with increasing frequency, being less for a 60 cycles than for 25 cycles. The carrying capacity of cables will therefore be less in hot climates than in cooler climates and will be considerably increased during the winter.

Cables immersed in water, carry at least 50 percent more than when installed in a four-duct line, and when buried in the earth 15 to 30 percent more than in a duct line, depending upon the character of soil moisture, etc. Circulating air or water through conduits containing lead covered cables will increase their capacity. From the above it is evident that no general rule relative to carrying capacity can be formulated to apply in all cases, and it is necessary, therefore, to consider carefully the surroundings when determining the size of cables to be used.

The practicability of tables which specify carrying capacity for cables installed in ducts will generally be questioned, for the reason that operating conditions are frequently more severe than those upon which table values are based. A duct line may operate at a safe temperature throughout its entire length, except at one isolated point adjacent to a steam pipe or excessive local temperatures due to some other cause. If larger cables are not employed at this point, burnouts may occur here when the remainder of the cable line is operating well within the limits of safe operating temperature. The danger in using table values for carrying capacity without carefully considering the condition of earth temperatures throughout the entire duct length is thus evident.

HEATING OF CABLES—TABLE XXIV

The basis upon which the data in Table XXIV has been calculated is covered by foot notes below the table. The kv-a values are determined from the current in amperes and are based upon 30 degree C rise and a maximum of 3000 volts.* Expressing the carrying capacity of cables in terms of kv-a (corrected for the varying thickness of insulation required for various voltages) may be found more convenient than the usual manner of expressing it in amperes. It will be noted that the kv-a values of the table are on the basis of a four-duct line and that for more than four ducts in the line the table kv-a values will be reduced to the following:—

For a 4 duct line—100 percent.
For a 6 duct line— 88 percent.
For an 8 duct line— 79 percent.
For a 10 duct line— 71 percent.
For a 12 duct line— 63 percent.
For a 16 duct line— 60 percent.

When applied to all sizes of cables, the above values are only approximate. The reduction of carrying capacity caused by the presence of many cables is more for large cables than for small ones. Also, where load factors are small, the reduction due to the presence of many cables is less than the value assigned, although the carrying capacity of a small number of cables is only slightly affected.

REACTANCE OF THREE-CONDUCTOR CABLES

Tables XXV and XXVI contain values for the inductance, reactance and impedance of round three-conductor cables of various sizes and for the thicknesses of insulation indicated.All values in the tables are on the basis of one conductor of the cable one mile long.

The table values were calculated from the fundamental equation (4),

$$L = 0.08047 + 0.741 \log \frac{D}{R}$$

where L = the inductance in millihenries per mile of each conductor, R the actual radius of the conductor and D the distance between conductor centers expressed in the same units as R. As indicated in Section I, under Inductance,** this formula has been derived on the basis of solid conductors. In the case of cables, the effective radius is actually slightly less than that of the stranded conductor. The values for

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*These current values are taken from General Electric Bulletin No. 49302 dated March 1917. They are in general slightly higher than those published by the Standard Underground Cable Company in their Hand Book dated 1906.

**July 1919, p. 287.

TABLE XXIV CARRYING CAPACITY OF INSULATED COPPER CONDUCTORS

The following values for carrying capacity must not be assumed unless it is positively known that the conditions upon which they are based will not be exceeded in service.

THREE CONDUCTOR CABLES

B & S NO AREA IN CIRCULAR MILS	XX [illegible] AND A MAXIMUM OF [illegible] VOLTS [illegible]	K V A WHICH MAY BE TRANSMITTED AT THREE PHASE AND THE FOLLOWING VOLTAGES OVER PAPER INSULATED LEAD COVERED CABLES INSTALLED IN A FOUR DUCT LINE WITH 30° C RISE IN TEMPERATURE BASED UPON THE ASSUMPTION THAT ALL DUCTS CARRY LOADED CABLES AND UPON A NORMAL EARTH TEMPERATURE OF 20° C. FOR A 6 DUCT LINE THESE K.V.A. VALUES WOULD BE REDUCED TO APPROXIMATELY 88 PER CENT FOR AN 8 DUCT LINE TO 79 PER CENT FOR A 10 DUCT LINE TO 71 PER CENT FOR A 12 DUCT LINE TO 63 PER CENT AND FOR A 16 DUCT LINE (4 WIDE AND 4 HIGH) TO 60 PER CENT OF THE TABLE VALUES X X X X																	
		220 VOLTS	440 VOLTS	550 VOLTS	1100 VOLTS	2200 VOLTS	3300 VOLTS	4000 VOLTS	6000 VOLTS	6600 VOLTS	10000 VOLTS	11000 VOLTS	12000 VOLTS	13200 VOLTS	15000 VOLTS	20000 VOLTS	22000 VOLTS	25000 VOLTS
14	18	7	14	17	34	68	103	124	184	202	300	328	356	390	438	570	620	693
12	22	8	17	21	42	84	125	152	225	247	367	400	435	477	536	695	757	847
10	30	11	23	28	57	114	171	206	307	336	500	547	595	650	730	950	1035	1155
8	40	15	30	38	76	152	228	275	410	450	667	730	792	867	975	1265	1380	1540
6	55	21	42	52	104	209	314	378	562	616	917	1000	1090	1190	1340	1740	1895	2120
4	70	26	53	66	133	266	400	482	715	785	1170	1275	1385	1520	1710	2215	2410	2700
2	95	36	72	90	180	361	543	655	970	1065	1585	1730	1880	2060	2310	3000	3270	3650
1	110	42	84	105	209	418	628	755	1125	1230	1840	2050	2180	2390	2680	3480	3780	4240
0	130	49	99	123	247	495	740	895	1330	1460	2170	2370	2580	2820	3170	4120	4470	5000
00	150	57	114	143	285	570	855	1030	1535	1710	2500	2740	2970	3260	3660	4750	5170	5770
000	170	65	130	162	323	647	970	1170	1740	1940	2840	3100	3370	3690	4150	5375	5850	6550
0000	200	76	152	190	380	760	1140	1375	2040	2240	3340	3650	3960	4340	4870	6325	6900	7700
250 000	225	86	172	214	428	857	1285	1550	2300	2520	3750	4100	4450	4880	5470	7125	7750	8650
300 000	250	95	190	238	475	950	1430	1720	2560	2800	4170	4550	4950	5425	6100	7900	8600	9625
350 000	280	106	213	266	532	1065	1600	1925	2860	3140	4670	5100	5550	6070	6825	8850	9650	10800
400 000	310	118	236	295	590	1180	1770	2130	3170	3480	5170	5650	6150	6720	7550	9800	10700	11950
450 000	340	129	258	323	647	1295	1940	2340	3480	3810	5670	6200	6750	7370	8300	10750	11700	13100
500 000	360	137	274	342	685	1370	2050	2480	3680	4040	6000	6550	7130	7800	8770	11400	12400	13850
600 000	400	152	304	380	760	1520	2280	2760	4100	4500	6680	7300	7920	8680	9750	12650	13800	15400
700 000	470	179	358	447	895	1790	2680	3240	4800	5270	7820	8570	9300	10200	11450	14850	16200	18100

SINGLE CONDUCTOR CABLES

B & S NO AREA IN CIRCULAR MILS	CARRYING CAPACITY IN AMPERES DIRECT CURRENT			K V A WHICH MAY BE TRANSMITTED AT THREE PHASE AND THE FOLLOWING VOLTAGES OVER THREE PAPER INSULATED LEAD COVERED CABLES INSTALLED IN A FOUR DUCT LINE WITH 30° C RISE IN TEMPERATURE BASED UPON THE ASSUMPTION THAT ALL DUCTS CARRY LOADED CABLES AND UPON A NORMAL EARTH TEMPERATURE OF 20° C. FOR A 6 DUCT LINE THESE K.V.A. VALUES WOULD BE REDUCED TO APPROXIMATELY 88 PER CENT FOR AN 8 DUCT LINE TO 79 PER CENT FOR A 10 DUCT LINE TO 71 PER CENT; FOR A 12 DUCT LINE TO 63 PER CENT AND FOR A 16 DUCT LINE (4 WIDE AND 4 HIGH) TO 60 PER CENT OF THE TABLE VALUES X X X X																	
	N E CODE INTERIOR CONDUCTORS		X X X																		
	X TABLE A RUBBER INSULATION	X TABLE B OTHER INSULATION	BASED UPON 30° C RISE & A MAXIMUM OF 3000 VOLTS PAPER INSULATION	220 VOLTS	440 VOLTS	550 VOLTS	1100 VOLTS	2200 VOLTS	3300 VOLTS	4000 VOLTS	6000 VOLTS	6600 VOLTS	10000 VOLTS	11000 VOLTS	12000 VOLTS	13200 VOLTS	15000 VOLTS	20000 VOLTS	22000 VOLTS	25000 VOLTS
14	15	20	24	9	18	23	46	92	137	165	245	270	400	437	475	520	585	758	826	925
12	20	25	30	11	23	28	57	114	171	206	306	337	500	547	595	650	732	948	1033	1155
10	25	30	40	15	30	38	76	152	228	275	408	450	667	730	792	868	975	1265	1378	1540
8	35	50	55	21	42	52	104	209	314	378	560	617	917	1010	1090	1195	1340	1740	1895	2120
7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6	50	70	75	28	57	71	142	284	428	515	765	842	1250	1270	1485	1630	1830	2370	2580	2890
5	55	80	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
4	70	90	95	36	72	90	181	362	540	653	970	1065	1585	1730	1880	2060	2320	3000	3270	3660
3	80	100	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2	90	125	125	47	95	119	237	475	712	860	1275	1405	2085	2280	2480	2710	3050	3950	4300	4820
1	100	150	150	57	114	143	285	570	855	1030	1530	1685	2500	2715	2970	3260	3660	4740	5170	5780
0	125	200	170	65	130	162	323	647	970	1170	1740	1910	2830	3100	3370	3690	4150	5380	5850	6550
00	150	225	200	76	152	190	380	760	1140	1380	2040	2280	3330	3650	3960	4350	4880	6320	6880	7700
000	175	275	230	87	175	219	437	875	1310	1580	2350	2620	3840	4200	4550	5000	5600	7270	7920	8860
0000	225	325	270	103	205	256	512	1025	1540	1860	2760	3030	4500	4920	5350	5850	6580	8530	9300	10400
250 000	—	—	300	114	228	285	570	1140	1710	2060	3070	3370	5000	5470	5950	6500	7320	9500	10350	11550
300 000	275	400	340	129	259	324	647	1295	1940	2340	3470	3820	5670	6200	6730	7380	8300	10750	11700	13200
350 000			380	144	289	362	723	1445	2170	2620	3880	4270	6330	6920	7520	8250	9260	12000	13100	14650
400 000	325	500	410	156	312	390	780	1560	2340	2820	4180	4600	6850	7480	8120	8900	10000	12950	14150	15800
450 000			450	172	343	428	855	1710	2560	3100	4600	5050	7500	8200	8900	9770	10900	14200	15500	17350
500 000	400	600	480	183	365	456	912	1825	2740	3300	4900	5400	8000	8750	9500	10400	11700	15200	16550	18500
600 000	450	680	550	209	418	522	1045	2090	3140	3790	5620	6180	9170	10000	10900	11950	13400	17400	18950	21200
700 000	500	760	610	232	464	580	1160	2320	3480	4200	6220	6850	10150	11100	12100	13250	14850	19300	21000	23500
800 000	550	840	670	255	510	638	1275	2550	3820	4600	6850	7520	11150	12200	13250	14550	16350	21200	23100	25800
900 000	600	920	720	274	548	685	1370	2740	4100	4950	7350	8100	12000	13150	14250	15650	17550	22700	24800	27700
1 000 000	650	1000	780	297	594	742	1480	2960	4450	5370	7950	8750	13000	14200	15450	16950	19000	24650	26800	30100
1 100 000	690	1080	-	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1 200 000	730	1150		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1 250 000	—	—	900	342	685	855	1710	3420	5130	6200	9200	10100	15000	16400	17800	19550	21900	28400	31000	34700
1 300 000	770	1220		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1 400 000	810	1290		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1 500 000	850	1360	1030	392	785	980	1960	3920	5870	7100	10500	11550	17200	18800	20400	22400	25100	32600	35500	39700
1 600 000	890	1430	-	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1 750 000	—	—	1130	430	860	1075	2150	4300	6450	7770	11550	12700	18800	20600	22400	24500	27500	35700	39000	43600
1 900 000	1010	16	-	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2 000 000	1050	1670	1260	480	960	1200	2400	4800	7200	8670	12850	14150	21000	23000	25000	27300	30700	39800	43300	48600

X For purposes of comparison these values are given for interior conductors.

XX For four conductor cables these ampere values would be reduced by 12.5 percent.

XXX For solid conductors these ampere ratings would be reduced by seven percent. For two conductor cables made up either round or flat, they would be reduced by 15 percent. For two conductor concentric cables they would be reduced by 25 percent. They will also be reduced in the case of the larger conductors when used on alternating-current circuits on account of skin effect, unless special cables having non-conducting cores are used. These special cables should be used for 700 000 circ. mils and larger for 60 cycle and 1 000 000 circ. mils and larger for 25 cycle service.

XXXX For the higher voltage cables the kv-a values of the table have been reduced by one percent for each 2000 volts that the working pressure exceeds 3000 volts, that is by 11 percent for a 25 000 volt cable. For insulated aluminum conductors the safe carrying capacity (based upon 61 percent conductivity) is 79.3 percent of the above table values with the same kind of insulation. These kv-a values are based upon the current in columns headed by XX and XXX.

TABLE XXV—INDUCTANCE, REACTANCE AND IMPEDANCE, AT 25 CYCLES, PER MILE OF SINGLE CONDUCTOR FOR THREE CONDUCTOR CABLES

AREA IN CIRCULAR MILS B & S NO.	DIAMETER IN INCHES	RESISTANCE PER MILE IN OHMS ★	INSULATION THICKNESS IN 64THS OF AN INCH ★★ $\frac{3}{64}$ BY $\frac{3}{64}$			$\frac{4}{64}$ BY $\frac{4}{64}$			$\frac{5}{64}$ BY $\frac{5}{64}$			$\frac{6}{64}$ BY $\frac{6}{64}$		
			IND. M.H.	REAC. OHMS	IMP. OHMS	IND. M.H.	REAC OHMS	IMP. OHMS	IND M H.	REAC. OHMS	IMP OHMS	IND M.H.	REAC. OHMS	IMP OHMS
500 000	.814	.116	.338	.0530	.128	.349	.0547	.129	.360	.0565	.129	.370	[illegible]	.130
450 000	.772	.129	.340	.0534	.140	.351	.0552	.140	.362	.0568	[illegible]	.373	.0585	.142
400 000	.728	.145	.343	.0537	.155	.354	.0554	.155	.367	.0576	.155	.377	[illegible]	[illegible]
350 000	.681	.166	.346	.0542	.175	.357	.0560	.176	.370	.0581	.176	.380	[illegible]	.177
300 000	.630	.194	.349	.0547	.204	.361	.0567	.204	.374	.0587	.205	.386	[illegible]	.207
250 000	.575	.233	.353	.0554	.240	.366	.0575	.240	.381	[illegible]	.240	[illegible]	[illegible]	[illegible]
0000	.528	.275	.357	.0560	.281	.372	.0585	.281	.387	[illegible]	[illegible]	.403	[illegible]	.282
000	.470	.346	.362	.0567	.352	.379	.0595	.352	.397	.0623	.352	.411	[illegible]	.353
00	.418	.437	.369	.0579	.441	.388	.0609	.442	.406	.0631	.442	.423	.0665	.442
0	.373	.550	.377	.0592	.552	.398	.0625	.554	.417	.0653	.554	.432	[illegible]	.554
1	.332	.695	.384	.0603	.697	.405	.0635	.698	.429	.0673	.698	.447	[illegible]	.699
2	.292	.879	.393	.0617	.882	.417	.0655	.882	.441	.0691	.882	.463	.0727	.882
3	.260	1.11	.403	.0633	1.11	.431	.0675	1.11	.454	.0712	1.11	.476	.0746	[illegible]
4	.232	1.40	.413	.0648	1.40	.442	.0695	1.40	.469	.0736	1.40	.494	.0775	[illegible]
6	.184	2.21	.437	.0685	2.21	.470	.0737	2.21	.501	.0785	2.21	.529	[illegible]	[illegible]

			$\frac{7}{64}$ BY $\frac{7}{64}$			$\frac{8}{64}$ BY $\frac{8}{64}$			$\frac{9}{64}$ BY $\frac{9}{64}$			$\frac{10}{64}$ BY $\frac{10}{64}$		
			IND M.H.	REAC. OHMS	IMP OHMS	IND. M H	REAC OHMS	IMP OHMS	IND M H.	REAC. OHMS	IMP. OHMS	IND. M.H.	REAC OHMS	IMP OHMS
500 000	.814	.116	.379	.0595	.130	.389	.0610	.131	.398	.0625	.132	.407	[illegible]	.133
450 000	.772	.129	.384	.0602	.143	.393	.0617	.143	.403	.0634	.144	.411	.0645	[illegible]
400 000	.728	.145	.389	.0610	.158	.396	.0622	.158	.409	.0642	.159	.417	[illegible]	[illegible]
350 000	.681	.166	.395	.0620	.177	.402	.0630	.178	.415	.0652	.178	.423	.0664	[illegible]
300 000	.630	.194	.399	.0626	.207	.409	.0642	.205	.421	.0660	.205	.431	.0675	.206
250 000	.575	.233	.409	.0642	.242	.419	.0658	.242	.430	.0675	.242	.442	[illegible]	.243
0000	.528	.275	.415	.0652	.283	.427	.0673	.283	.441	.0690	.284	.452	.0708	.285
000	.470	.346	.429	.0673	.353	.440	.0690	.353	.455	.0714	.354	.466	.0730	.355
00	.418	.437	.439	.0690	.443	.455	.0714	.443	.469	.0735	.443	.483	.0758	.444
0	.373	.550	.453	.0712	.554	.466	.0731	.554	.485	.0760	.555	.498	.0780	.556
1	.332	.695	.466	.0732	.698	.483	.0757	.697	.501	.0785	.699	.516	.0810	.700
2	.292	.879	.483	.0758	.882	.502	.0787	.882	.521	.0816	.833	.537	.0843	.833
3	.260	1.11	.499	.0782	1.11	.519	.0814	1.11	.538	.0845	1.11	.558	.0875	1.11
4	.232	1.40	.518	.0813	1.40	.538	.0845	1.40	.558	.0875	1.40	.577	.0905	1.40
6	.184	2.21	.557	.0873	2.21	.580	.0910	2.21	.601	.0943	2.21	[illegible]	.0975	2.21

			$\frac{11}{64}$ BY $\frac{11}{64}$			$\frac{12}{64}$ BY $\frac{12}{64}$			$\frac{13}{64}$ BY $\frac{13}{64}$			$\frac{14}{64}$ BY $\frac{14}{64}$		
			IND. M.H.	REAC. OHMS	IMP. OHMS	IND. M.H.	REAC. OHMS	IMP. OHMS	IND. M.H.	REAC. OHMS	IMP. OHMS	IND. M H.	REAC OHMS	IMP OHMS
500 000	.814	.116	.417	.0655	.133	.427	.0670	.133	.434	.0681	.134	.441	.0691	[illegible]
450 000	.772	.129	.423	.0665	.145	.431	.0675	.145	.439	.0690	.146	.449	[illegible]	.147
400 000	.728	.145	.429	.0673	.160	.436	.0683	.160	.446	.0700	.161	.457	[illegible]	.162
350 000	.681	.166	.436	.0685	.180	.446	.0700	.180	.453	.0710	.180	.464	.0729	.181
300 000	.630	.194	.444	.0697	.206	.456	.0715	.206	.461	.0722	.207	.473	.0742	.208
250 000	.575	.233	.454	.0712	.244	.465	.0730	.244	.475	.0745	.245	.486	.0762	[illegible]
0000	.528	.275	.465	.0730	.285	.476	.0745	.285	.486	.0760	.286	.498	.0782	.287
000	.470	.346	.481	.0755	.355	.493	.0775	.355	.503	.0790	.355	.516	.0810	.356
00	.418	.437	.498	.0780	.445	.510	.0800	.445	.521	.0816	.445	.535	.0840	.446
0	.373	.550	.514	.0805	.556	.528	.0828	.556	.539	.0845	.556	.554	.0870	[illegible]
1	.332	.695	.531	.0830	.700	.546	.0855	.700	.559	.0877	.700	.573	.0900	.700
2	.292	.879	.554	.0870	.882	.570	.0895	.882	.583	.0915	.883	.598	.0938	.884
3	.260	1.11	.574	.0900	1.11	.591	.0927	1.11	.606	.0950	1.11	.618	.0970	[illegible]
4	.232	1.40	.596	.0935	1.40	.613	.0962	1.40	.627	.0983	1.40	.643	[illegible]	[illegible]
6	.184	2.21	.643	.1010	2.21	.661	.1037	2.21	.678	.1063	2.21	.696	[illegible]	[illegible]

			$\frac{16}{64}$ BY $\frac{16}{64}$			$\frac{18}{64}$ BY $\frac{18}{64}$			$\frac{20}{64}$ BY $\frac{20}{64}$			$\frac{22}{64}$ BY $\frac{22}{64}$		
			IND. M.H.	REAC. OHMS	IMP. OHMS	IND. M.H.	REAC. OHMS	IMP. OHMS	IND M.H.	REAC. OHMS	IMP. OHMS	IND. M.H.	REAC.. OHMS	IMP OHMS
500 000	.814	.116	.457	.0717	.136	.474	.0744	.138	.487	.0764	.140	[illegible]	.0785	.141
450 000	.772	.129	.462	.0725	.148	.481	.0754	.150	.496	.0778	.151	.509	.0800	.152
400 000	.728	.145	.471	.0738	.163	.487	.0764	.164	.505	.0792	.165	.519	[illegible]	[illegible]
350 000	.681	.166	.480	.0753	.182	.496	.0778	.183	.513	.0805	.185	.529	.0830	[illegible]
300 000	.630	.194	.491	.0770	.208	.511	.0802	.210	.526	.0825	.211	.541	[illegible]	[illegible]
250 000	.575	.233	.505	.0792	.246	.524	.0822	.247	.541	.0848	.248	.557	[illegible]	.249
0000	.528	.275	.517	.0810	.287	.536	.0840	.288	.556	.0870	.289	[illegible]	.0900	.290
000	.470	.346	.536	.0840	.357	.556	.0870	.357	.575	.0905	.358	[illegible]	.0930	.360
00	.418	.437	.552	.0865	.446	.578	.0907	.446	.599	.0940	.447	[illegible]	[illegible]	.448
0	.373	.550	.575	.0902	.558	.601	.0942	.558	.621	.0972	.558	[illegible]	[illegible]	.559
1	.332	.695	.598	.0938	.700	.623	.0980	.700	.645	.1010	.701	[illegible]	[illegible]	.702
2	.292	.879	.623	.0978	.884	.649	.1017	.884	.674	.1060	.885	[illegible]	[illegible]	.886
3	.260	1.11	.649	.1018	1.11	.674	.1060	1.11	.698	.1095	[illegible]	[illegible]	.1130	1.12
4	.232	1.40	.673	.1055	1.41	.701	.1100	1.41	.725	.1138	[illegible]	[illegible]	.1170	[illegible]
6	.184	2.21	.725	.1135	2.22	.754	.1180	2.22	.780	.1225	2.22	[illegible]	.1270	2.22

*Resistance based upon 100 percent conductivity at 25 degrees C (77 degrees F), including two percent allowance for spiral of strands and two percent allowance for spiral of conductors. For a temperature of 65 degrees C (149 degrees F) these resistance values would be increased 15 percent.

**The inductance is in millihenries; the reactance and the impedance are in ohms.

The table values were derived from the equation $L = 0.08047 + 0.741\ Log_{10} \frac{D}{R}$ where R is the radius of conductor, D the distance between centers of conductors expressed in the same terms as R, and L the inductance in millihenries per mile of each conductor. All values in the table are single-phase and based upon a single conductor one mile long.

TABLE XXVI INDUCTANCE, REACTANCE AND IMPEDANCE, AT 60 CYCLES, PER MILE OF SINGLE CONDUCTOR FOR THREE CONDUCTOR CABLES

AREA IN CIRCULAR MILS B & S NO.	DIAMETER IN INCHES	RESISTANCE PER MILE IN OHMS ★	INSULATION THICKNESS IN 64THS OF AN INCH ★★											
			$\frac{3}{64}$ BY $\frac{3}{64}$			$\frac{4}{64}$ BY $\frac{4}{64}$			$\frac{5}{64}$ BY $\frac{5}{64}$			$\frac{6}{64}$ BY $\frac{6}{64}$		
			IND M H	REAC. OHMS	IMP OHMS	IND. M H.	REAC. OHMS	IMP OHMS	IND. M H.	REAC. OHMS	IMP. OHMS	IND. M.H.	REAC. OHMS	IMP OHMS
500 000	.814	.116	.338	.127	.172	.349	.131	.175	.360	.136	.178	.370	.140	.182
450 000	.772	.129	.340	.128	.182	.351	.132	.184	.362	.137	.189	.373	.141	.191
400 000	.728	.145	.343	.129	.195	.354	.134	.197	.367	.138	.201	.377	.142	.204
350 000	.681	.166	.346	.130	.211	.357	.135	.214	.370	.140	.217	.380	.143	.220
300 000	.630	.194	.349	.132	.235	.361	.136	.237	.374	.141	.240	.386	.145	.244
250 000	.575	.233	.353	.133	.268	.366	.138	.271	.381	.144	.274	.394	.149	.277
0000	.528	.275	.357	.135	.306	.372	.140	.309	.387	.146	.313	.403	.152	.316
000	.470	.346	.362	.136	.373	.379	.143	.375	.397	.150	.378	.411	.155	.381
00	.418	.437	.369	.139	.459	.388	.146	.461	.406	.153	.464	.423	.160	.466
0	.373	.550	.377	.142	.569	.398	.150	.571	.417	.157	.572	.432	.163	.573
1	.332	.695	.384	.145	.710	.405	.152	.713	.429	.162	.715	.447	.168	.716
2	.292	.879	.393	.148	.893	.417	.157	.894	.441	.166	.896	.463	.174	.896
3	.260	1.11	.403	.152	1.12	.431	.162	1.12	.454	.171	1.12	.476	.180	1.12
4	.232	1.40	.413	.156	1.41	.442	.167	1.41	.469	.177	1.41	.494	.186	1.41
6	.184	2.21	.437	.165	2.22	.470	.177	2.22	.501	.189	2.22	.529	.200	2.22

			$\frac{7}{64}$ BY $\frac{7}{64}$			$\frac{8}{64}$ BY $\frac{8}{64}$			$\frac{9}{64}$ BY $\frac{9}{64}$			$\frac{10}{64}$ BY $\frac{10}{64}$		
			IND. M H.	REAC. OHMS	IMP OHMS	IND. M.H.	REAC. OHMS	IMP. OHMS	IND. M.H.	REAC. OHMS	IMP. OHMS	IND. M.H.	REAC. OHMS	IMP OHMS
500 000	.814	.116	.379	.143	.184	.389	.146	.186	.398	.150	.190	.407	.153	.192
450 000	.772	.129	.384	.145	.194	.393	.148	.195	.403	.152	.200	.411	.155	.202
400 000	.728	.145	.389	.147	.206	.396	.149	.208	.409	.154	.212	.417	.157	.230
350 000	.681	.166	.395	.149	.222	.402	.151	.224	.415	.157	.229	.423	.160	.231
300 000	.630	.194	.399	.150	.240	.409	.154	.246	.421	.158	.251	.431	.162	.254
250 000	.575	.233	.409	.154	.279	.419	.158	.282	.430	.162	.285	.442	.166	.286
0000	.528	.275	.415	.157	.318	.427	.161	.320	.441	.166	.323	.452	.170	.323
000	.470	.346	.429	.162	.383	.440	.166	.385	.455	.172	.388	.466	.176	.389
00	.418	.437	.439	.166	.467	.455	.171	.471	.469	.177	.473	.483	.182	.474
0	.373	.550	.453	.171	.578	.466	.176	.578	.485	.183	.580	.498	.188	.582
1	.332	.695	.466	.176	.718	.483	.182	.697	.501	.189	.720	.516	.195	.721
2	.292	.879	.483	.182	.900	.502	.189	.900	.521	.196	.902	.537	.202	.902
3	.260	1.11	.499	.188	1.13	.519	.195	1.13	.538	.203	1.13	.558	.211	1.13
4	.232	1.40	.518	.195	1.41	.538	.203	1.41	.558	.210	1.42	.577	.218	1.42
6	.184	2.21	.557	.210	2.22	.580	.219	2.22	.601	.226	2.22	.622	.234	2.22

			$\frac{11}{64}$ BY $\frac{11}{64}$			$\frac{12}{64}$ BY $\frac{12}{64}$			$\frac{13}{64}$ BY $\frac{13}{64}$			$\frac{14}{64}$ BY $\frac{14}{64}$		
			IND. M.H.	REAC. OHMS	IMP. OHMS	IND. M.H.	REAC OHMS	IMP. OHMS	IND M.H.	REAC OHMS	IMP. OHMS	IND. M H.	REAC OHMS	IMP. OHMS
500 000	.814	.116	.417	.157	.195	.427	.161	.198	.434	.164	.202	.441	.166	.202
450 000	.772	.129	.423	.160	.204	.431	.162	.208	.439	.165	.211	.449	.170	.213
400 000	.728	.145	.429	.161	.216	.436	.164	.220	.446	.168	.222	.457	.172	.224
350 000	.681	.166	.436	.164	.235	.446	.168	.237	.453	.171	.240	.464	.175	.240
300 000	.630	.194	.444	.167	.256	.456	.172	.260	.461	.174	.262	.473	.178	.264
250 000	.575	.233	.454	.171	.289	.465	.175	.292	.475	.179	.295	.486	.183	.296
0000	.528	.275	.465	.175	.328	.476	.180	.330	.486	.183	.332	.498	.188	.334
000	.470	.346	.481	.181	.392	.493	.186	.395	.503	.190	.396	.516	.194	.398
00	.418	.437	.498	.188	.476	.510	.192	.479	.521	.196	.480	.535	.202	.482
0	.373	.550	.514	.194	.584	.528	.199	.586	.539	.203	.589	.554	.209	.590
1	.332	.695	.531	.200	.724	.546	.206	.725	.559	.211	.726	.573	.216	.728
2	.292	.879	.554	.209	.905	.570	.215	.906	.583	.220	.908	.598	.225	.910
3	.260	1.11	.574	.216	1.13	.591	.222	1.13	.606	.228	1.13	.618	.233	1.14
4	.232	1.40	.596	.224	1.42	.613	.231	1.42	.627	.236	1.42	.643	.242	1.42
6	.184	2.21	.643	.242	2.22	.661	.249	2.22	.678	.256	2.22	.696	.262	2.23

			$\frac{16}{64}$ BY $\frac{16}{64}$			$\frac{18}{64}$ BY $\frac{18}{64}$			$\frac{20}{64}$ BY $\frac{20}{64}$			$\frac{22}{64}$ BY $\frac{22}{64}$		
			IND M H.	REAC OHMS	IMP. OHMS	IND M.H.	REAC OHMS	IMP OHMS	IND. M.H.	REAC OHMS	IMP OHMS	IND. M.H.	REAC OHMS	IMP OHMS
500 000	.814	.116	.457	.172	.208	.474	.179	.212	.487	.183	.217	.501	.189	.222
450 000	.772	.129	.462	.174	.218	.481	.181	.224	.496	.187	.228	.509	.192	.232
400 000	.728	.145	.471	.178	.230	.487	.183	.235	.505	.190	.240	.519	.196	.244
350 000	.681	.166	.480	.181	.246	.496	.187	.252	.513	.193	.254	.529	.200	.260
300 000	.630	.194	.491	.185	.270	.511	.192	.274	.526	.198	.279	.541	.204	.282
250 000	.575	.233	.505	.190	.302	.524	.197	.306	.541	.204	.311	.557	.210	.314
0000	.528	.275	.517	.195	.338	.536	.202	.342	.556	.210	.348	.573	.216	.352
000	.470	.346	.536	.202	.403	.556	.209	.406	.575	.217	.410	.592	.223	.415
00	.418	.437	.552	.208	.486	.578	.218	.490	.599	.226	.494	.618	.233	.496
0	.373	.550	.575	.217	.592	.601	.226	.596	.621	.234	.599	.641	.242	.602
1	.332	.695	.598	.225	.732	.623	.235	.734	.645	.243	.737	.666	.251	.740
2	.292	.879	.623	.235	.912	.649	.245	.914	.674	.254	.917	.693	.261	.920
3	.260	1.11	.649	.245	1.14	.674	.254	1.14	.698	.262	1.14	.721	.272	1.14
4	.232	1.40	.673	.254	1.42	.701	.264	1.43	.725	.273	1.43	.746	.281	1.43
6	.184	2.21	.725	.273	2.22	.754	.284	2.23	.780	.294	2.23	.809	.305	2.23

*Resistance based upon 100 percent conductivity at 25 degrees C (77 degrees F), including two percent allowance for spiral of strands and two percent allowance for spiral of conductors. For a temperature of 65 degrees C (149 degrees F) these resistance values would be increased 15 percent.

**The inductance is in millihenries; the reactance and the impedance are in ohms.

The table values were derived from the equation $L = 0.08047 + 0.741 \, Log_{10} \frac{D}{R}$ where R is the radius of conductor, D the distance between centers of conductors expressed in the same terms as R, and L the inductance in millihenries per mile of each conductor. All values in the table are single-phase and based upon a single conductor one mile long.

inductance, as determined by the fundamental formula, would thus tend to give values several percent less than the actual when applied to three-conductor cable calculations. On the other hand spiraling the conductors of three conductor cables tends to increase their reactance by several percent. It may, therefore, be assumed that the use of the fundamental formula in the case of three-conductor cables give results approximately correct. Skin effect on the larger cables will, however, tend to decrease the reactance slightly, particularly at 60 cycles.

CAPACITANCE OF 3 CONDUCTOR CABLES

Formulas for determining the approximate capacitance of three-conductor cables are cumbersome. They give reasonably accurate results only in the case of a homogeneous dielectric and in cases where the conductors are small compared to the radius of the sheath. They give inaccurate results in cases of large conductors closely spaced. Fig. 58* illustrates the various capacitances of a three-conductor cable. Formulas taken from Russel's "Alternating Currents" have been combined and converted to common logarithms and are given below. They were derived by the method of images and on the assumption that the conductors are round and symmetrically spaced with respect to the axis of the sheath.

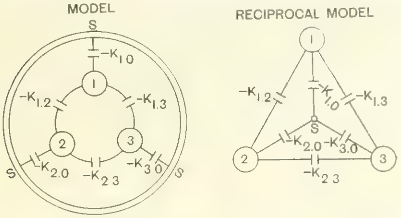

FIG. 58—REPRESENTATION OF CAPACITANCES OF A SYMMETRICAL THREE-PHASE CABLE

$$C_1 = \frac{1}{13.82 \, log_{10} \dfrac{R^6 - d^6}{3 \, R^3 \, d^2 \, r}} + \frac{1}{6.91 \, log_{10} \left(\dfrac{1.73d}{r} \times \dfrac{R^2 - d^2}{(R^4 + R^2 d^2 + d^4)^{1/2}} \right)} \times 0.179 \times K \, . \quad (70)$$

$$C_{12} = \frac{1}{13.82 \, log_{10} \dfrac{R^6 - d^6}{3 \, R^3 \, d^2 \, r}} - \frac{1}{13.82 \, log_{10} \left(\dfrac{1.73d}{r} \times \dfrac{R^2 - d^2}{(R^4 + R^2 d^2 + d^4)^{1/2}} \right)} \times 0.179 \times K \quad (71)$$

Where,—

R = inside radius of sheath in centimeters (Fig. 59).
r = radius of conductor in centimeters.
d = distance between axis of conductor and axis of sheath in centimeters.
K = the dielectric constant. For impregnated paper insulation it varies between 3 and 4; for varnished cambric insulation it varies between 4 and 6; for rubber insulation it varies between 4 and 9.
C_1 = capacitance in microfarads per mile between one conductor and the other two conductors plus the sheath.
C_{1-2} = mutual capacitance in microfarads per mile between any two conductors. The capacitance to neutral is twice this value.
C_{12} is used in determining the capacitance for various combinations or arrangements as explained below.

CAPACITANCE AND SUSCEPTANCE—TABLE XXVII

Table XXVII contains values for capacitance and susceptance of three conductor paper insulated cable for the various sizes of conductors and thicknesses of insulation indicated. All values are based upon a value for *K of 3.5* and, as indicated, a thickness of insulation for the jacket the same as that surrounding each conductor. The values were calculated by equations (70) and (71).

The susceptance values given for 25 and 60 cycles are to neutral. In calculating the voltage regulation of circuits, it is general practice to calculate the regulation on the basis of one conductor to neutral. The susceptance between two of the conductors would be half the table values to neutral. The values for susceptance were calculated from the equation,—

Susceptance to neutral in micromhos $= 2 \pi f C$

Thus No. 0 three-conductor cable with 7/64 and 7/64 insulation has a capacitance between conductors of 0.195 microfarads (0.39 microfarads to neutral). The susceptance to neutral at 60 cycles therefore is,— $2 \pi 60 \times 0.39 = 147$ microfarads, as indicated by the table.

INTER-RELATION OF CAPACITANCE OF THREE-CONDUCTOR CABLES

The following equations for determining the effective capacitance for various arrangements of the three conductors and the sheath are given in Russell's "Alternating Currents."

Capacitance between 1 and 2 $= \frac{1}{2} (C_1 - C_{12})$ ...... (72)

Capacitance between 1 and 2, 3 $= \frac{2}{3} (C_1 - C_{12})$ .... (73)

Capacitance between 1 and S (2 and 3 insulated) $= \dfrac{(C_1 - C_{12}) \; (C_1 + 2 \, C_{12})}{C_1 + C_{12}}$ .... (74)

Capacitance between 1 and S, 2 (3 insulated) $= \dfrac{(C_1 - C_{12}) \; (C_1 + C_{12})}{C_1}$ .... (75)

Capacitance between 1 and S, 2, 3 $= C_1$ .... (76)

Capacitance between S and 1, 2, (3 insulated) $= \dfrac{2 \; (C_1 - C_{12}) \; (C_1 + 2 \, C_{12})}{C_1}$ .... (77)

Capacitance between 1, S and 2, 3 $= 2 \; (C_1 + C_{12})$.... (78)

Capacitance between S and 1, 2, 3 $= 3 \; (C_1 + 2C_{12})$... (79)

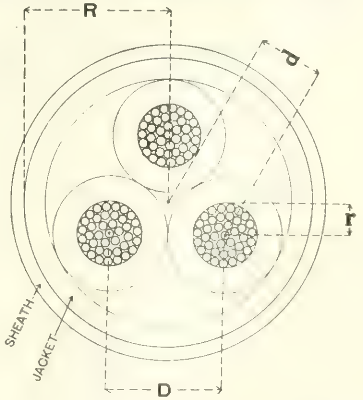

FIG. 59—DIMENSIONS OF A SYMMETRICAL THREE-PHASE CABLE

C_1 (76) may be measured in the ordinary way, by reading the throw of a mirror galvanometer and comparing with the throw given by a standard condenser. A further measurement of (78) or (79) will give a simple equation to find C_{12}. For instance, if measurements were taken of (78) and (79) and were found to be:—

---

*Reproduced from Alexander Russel's "Alternating Currents."

TABLE XXVII—CAPACITANCE AND SUSCEPTANCE PER MILE OF THREE CONDUCTOR PAPER INSULATED CABLES

AREA IN CIRCULAR MILS	INSULATION THICKNESS IN 64THS OF AN INCH																			
	$\frac{3}{64}$ BY $\frac{3}{64}$					$\frac{4}{64}$ BY $\frac{4}{64}$					$\frac{5}{64}$ BY $\frac{5}{64}$					$\frac{6}{64}$ BY $\frac{6}{64}$				
	CAPACITANCE			SUSCEPTANCE TO NEUTRAL		CAPACITANCE			SUSCEPTANCE TO NEUTRAL		CAPACITANCE			SUSCEPTANCE TO NEUTRAL		CAPACITANCE			SUSCEPTANCE TO NEUTRAL	
B & S NO.	C_1	C_{12}	$C_{1\&2}$	25 CYCLES	60 CYCLES	C_1	C_{12}	$C_{1\&2}$	25 CYCLES	60 CYCLES	C_1	C_{12}	$C_{1\&2}$	25 CYCLES	60 CYCLES	C_1	C_{12}	$C_{1\&2}$	25 CYCLES	60 CYCLES
500 000	[illegible]	-.217	.448	141	[illegible]	[illegible]	-.175	.394	[illegible]	[illegible]	[illegible]	-.154	.354	111	267	[illegible]	-.137	.321	101	242
450 000	[illegible]	-.197	[illegible]	136	[illegible]	[illegible]	-.169	[illegible]	119	[illegible]	.538	-.149	[illegible]	108	259	.498	-.130	.304	97	233
400 000	[illegible]	-.194	[illegible]	133	320	.570	[illegible]	[illegible]	114	274	.517	-.142	[illegible]	103	248	[illegible]	-.125	.300	[illegible]	226
350 000	[illegible]	-.189	[illegible]	130	313	.560	[illegible]	.359	113	270	[illegible]	-.138	.322	[illegible]	[illegible]	[illegible]	-.119	.289	91	218
300 000	[illegible]	[illegible]	[illegible]	123	294	[illegible]	-.153	.349	[illegible]	[illegible]	[illegible]	-.131	[illegible]	[illegible]	[illegible]	.446	[illegible]	[illegible]	88	[illegible]
250 000	.590	[illegible]	[illegible]	120	286	[illegible]	-.142	.330	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	223	.427	-.109	[illegible]	84	202
0000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-.134	[illegible]	100	[illegible]	[illegible]	[illegible]	[illegible]	88	[illegible]	.407	[illegible]	.255	80	192
000	.535	[illegible]	.341	107	[illegible]	.475	[illegible]	[illegible]	[illegible]	226	.420	-.107	.262	82	[illegible]	.384	[illegible]	.239	75	180
00	.513	[illegible]	.327	103	[illegible]	.447	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.249	78	187	[illegible]	[illegible]	.226	71	170
0	[illegible]	[illegible]	[illegible]	97	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.374	-.090	[illegible]	73	[illegible]	[illegible]	[illegible]	.211	[illegible]	[illegible]
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	78	187	[illegible]	[illegible]	.221	[illegible]	167	.323	-.074	.198	62	[illegible]
2	[illegible]	-.107	[illegible]	[illegible]	[illegible]	[illegible]	-.091	[illegible]	[illegible]	175	.332	-.077	[illegible]	64	153	[illegible]	[illegible]	.187	59	141
3	[illegible]	-.101	.251	[illegible]	[illegible]	[illegible]	-.084	.218	69	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	145	.284	[illegible]	.173	54	[illegible]
4	.378	[illegible]	.239	[illegible]	[illegible]	.330	-.077	[illegible]	64	153	.295	[illegible]	[illegible]	57	[illegible]	[illegible]	-.059	[illegible]	52	[illegible]
6	[illegible]	-.081	[illegible]	66	[illegible]	.301	-.063	[illegible]	57	137	.264	[illegible]	.160	50	[illegible]	.239	-.050	[illegible]	45	108

	$\frac{7}{64}$ BY $\frac{7}{64}$					$\frac{8}{64}$ BY $\frac{8}{64}$					$\frac{9}{64}$ BY $\frac{9}{64}$					$\frac{10}{64}$ BY $\frac{10}{64}$				
	CAPACITANCE			SUSCEPTANCE TO NEUTRAL		CAPACITANCE			SUSCEPTANCE TO NEUTRAL		CAPACITANCE			SUSCEPTANCE TO NEUTRAL		CAPACITANCE			SUSCEPTANCE TO NEUTRAL	
	C_1	C_{12}	$C_{1\&2}$	25 CYCLES	60 CYCLES	C_1	C_{12}	$C_{1\&2}$	25 CYCLES	60 CYCLES	C_1	C_{12}	$C_{1\&2}$	25 CYCLES	60 CYCLES	C_1	C_{12}	$C_{1\&2}$	25 CYCLES	60 CYCLES
500 000	[illegible]	[illegible]	[illegible]	[illegible]	224	.435	-.115	.275	86	207	.410	-.104	.257	81	193	.392	-.097	.244	[illegible]	[illegible]
450 000	[illegible]	-.119	[illegible]	90	216	.427	-.107	.267	84	201	.405	-.103	.254	79	191	.380	[illegible]	.236	[illegible]	178
400 000	[illegible]	-.116	.279	88	210	[illegible]	-.105	.260	82	196	[illegible]	-.099	[illegible]	77	[illegible]	.368	[illegible]	.229	72	173
350 000	.426	[illegible]	.267	84	201	.398	-.099	.248	78	187	.380	-.093	.236	74	[illegible]	.358	[illegible]	.222	70	[illegible]
300 000	[illegible]	[illegible]	.260	82	196	.390	-.096	.243	76	183	.365	-.089	.227	[illegible]	[illegible]	[illegible]	[illegible]	.215	68	[illegible]
250 000	[illegible]	[illegible]	[illegible]	79	188	[illegible]	-.089	.229	72	173	[illegible]	-.087	.219	69	165	.332	-.078	.205	65	[illegible]
0000	[illegible]	[illegible]	.237	75	178	.354	-.085	.220	69	166	.334	[illegible]	.205	64	[illegible]	.316	-.073	.194	61	146
000	[illegible]	[illegible]	.222	70	168	.332	-.079	.205	64	155	.315	-.073	.194	61	146	.296	-.066	.181	57	136
00	[illegible]	[illegible]	.208	[illegible]	157	.313	-.071	.192	60	145	.295	[illegible]	[illegible]	57	[illegible]	.278	-.061	.169	53	[illegible]
0	[illegible]	-.073	[illegible]	[illegible]	147	.293	-.065	.179	56	135	[illegible]	[illegible]	[illegible]	54	128	.263	-.056	.159	50	120
1	[illegible]	-.068	[illegible]	58	138	.280	-.061	.170	54	128	.261	[illegible]	.158	50	119	.247	[illegible]	.151	47	[illegible]
2	[illegible]	[illegible]	[illegible]	54	128	.264	-.056	.160	50	121	[illegible]	-.052	.150	47	113	.233	-.048	.140	44	106
3	[illegible]	-.056	.160	50	121	.248	-.052	.150	47	113	.232	[illegible]	.140	44	[illegible]	.222	-.044	.133	42	100
4	[illegible]	-.053	.151	47	114	.233	-.048	[illegible]	44	106	.221	-.045	.133	42	100	.210	-.041	[illegible]	39	[illegible]
6	[illegible]	-.045	.133	42	100	.204	-.041	.125	39	94	[illegible]	[illegible]	.117	37	88	[illegible]	-.036	.112	35	85

	$\frac{11}{64}$ BY $\frac{11}{64}$					$\frac{12}{64}$ BY $\frac{12}{64}$					$\frac{13}{64}$ BY $\frac{13}{64}$					$\frac{14}{64}$ BY $\frac{14}{64}$				
	CAPACITANCE			SUSCEPTANCE TO NEUTRAL		CAPACITANCE			SUSCEPTANCE TO NEUTRAL		CAPACITANCE			SUSCEPTANCE TO NEUTRAL		CAPACITANCE			SUSCEPTANCE TO NEUTRAL	
	C_1	C_{12}	$C_{1\&2}$	25 CYCLES	60 CYCLES	C_1	C_{12}	$C_{1\&2}$	25 CYCLES	60 CYCLES	C_1	C_{12}	$C_{1\&2}$	25 CYCLES	60 CYCLES	C_1	C_{12}	$C_{1\&2}$	25 CYCLES	60 CYCLES
	.371	[illegible]	.230	72	173	.355	-.085	.220	69	166	.343	-.082	.212	67	160	.329	-.078	.203	[illegible]	[illegible]
450 000	[illegible]	[illegible]	[illegible]	[illegible]	170	.352	-.085	.218	68	164	.332	-.078	.205	64	155	.321	[illegible]	.198	62	149
400 000	[illegible]	[illegible]	.220	69	166	.338	-.080	.209	66	157	.326	-.076	.201	63	152	.310	-.071	[illegible]	[illegible]	[illegible]
[illegible]	.340	[illegible]	.210	66	[illegible]	.328	-.077	.202	63	152	.317	-.073	.195	61	147	.300	-.068	.184	58	139
[illegible]	[illegible]	[illegible]	.203	64	[illegible]	.313	-.071	.192	60	145	.303	-.069	.186	59	[illegible]	.290	-.065	.177	56	133
250 000	[illegible]	-.072	[illegible]	[illegible]	[illegible]	[illegible]	-.068	.183	[illegible]	138	.288	-.064	.176	55	[illegible]	.276	[illegible]	[illegible]	53	[illegible]
0000	[illegible]	[illegible]	[illegible]	[illegible]	140	[illegible]	-.067	[illegible]	[illegible]	[illegible]	.278	[illegible]	.169	53	[illegible]	.264	[illegible]	.160	50	121
000	[illegible]	[illegible]	[illegible]	54	[illegible]	.271	-.060	[illegible]	52	[illegible]	.261	[illegible]	.158	50	119	.251	-.053	[illegible]	48	[illegible]
00	[illegible]	[illegible]	[illegible]	[illegible]	122	.255	-.054	.154	[illegible]	116	.247	[illegible]	.150	47	113	[illegible]	-.048	.142	45	[illegible]
	[illegible]	-.053	[illegible]	[illegible]	[illegible]	.241	-.050	[illegible]	46	109	.233	-.048	.140	44	106	.222	-.044	.133	42	100
	[illegible]	[illegible]	.143	[illegible]	[illegible]	.228	-.047	.137	43	[illegible]	.220	[illegible]	.132	42	[illegible]	.212	[illegible]	.127	40	[illegible]
	[illegible]	[illegible]	.133	42	100	.216	-.044	.130	41	98	.208	-.041	[illegible]	39	94	.199	[illegible]	[illegible]	37	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.204	-.039	[illegible]	38	91	.195	-.037	.116	36	88	.190	[illegible]	.113	[illegible]	85
4	.201	[illegible]	.120	[illegible]	[illegible]	.192	[illegible]	.114	36	86	.186	-.034	.110	35	83	.180	-.033	.106	33	80
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.174	-.031	.102	32	77	.168	-.030	.099	31	[illegible]	.163	[illegible]	.096	30	73

	$\frac{16}{64}$ BY $\frac{16}{64}$					$\frac{18}{64}$ BY $\frac{18}{64}$					$\frac{20}{64}$ BY $\frac{20}{64}$					$\frac{22}{64}$ BY $\frac{22}{64}$				
	CAPACITANCE			SUSCEPTANCE TO NEUTRAL		CAPACITANCE			SUSCEPTANCE TO NEUTRAL		CAPACITANCE			SUSCEPTANCE TO NEUTRAL		CAPACITANCE			SUSCEPTANCE TO NEUTRAL	
	C_1	C_{12}	$C_{1\&2}$	25	60 CYCLES	C_1	C_{12}	$C_{1\&2}$	25 CYCLES	60 CYCLES	C_1	C_{12}	$C_{1\&2}$	25 CYCLES	60 CYCLES	C_1	C_{12}	$C_{1\&2}$	25 CYCLES	60 CYCLES
500 000	[illegible]	[illegible]	[illegible]	[illegible]	143	.288	[illegible]	.176	55	133	.276	[illegible]	[illegible]	53	[illegible]	.263	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	-.069	[illegible]	[illegible]	[illegible]	[illegible]	-.062	.172	54	[illegible]	.269	[illegible]	.163	51	[illegible]	.255	[illegible]	[illegible]	48	116
[illegible]	[illegible]	-.066	[illegible]	[illegible]	[illegible]	[illegible]	-.060	[illegible]	53	[illegible]	.260	-.055	.157	50	[illegible]	[illegible]	-.053	.151	47	[illegible]
[illegible]	.282	[illegible]	[illegible]	[illegible]	[illegible]	.266	[illegible]	[illegible]	51	121	[illegible]	-.053	.152	48	[illegible]	.240	-.049	.144	45	[illegible]
300 000	.271	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-.054	[illegible]	49	117	.242	-.050	[illegible]	46	110	[illegible]	[illegible]	.139	44	105
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-.051	[illegible]	46	111	[illegible]	[illegible]	.139	44	105	.222	[illegible]	.133	42	100
0000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.233	-.049	[illegible]	44	106	.222	[illegible]	[illegible]	42	100	[illegible]	[illegible]	.126	40	[illegible]
000	.234	[illegible]	[illegible]	[illegible]	[illegible]	.221	-.044	.132	42	100	.211	[illegible]	.126	40	[illegible]	.200	-.038	[illegible]	38	[illegible]
00	[illegible]	[illegible]	.133	[illegible]	100	[illegible]	-.041	[illegible]	39	94	.199	[illegible]	.118	37	[illegible]	[illegible]	[illegible]	[illegible]	36	[illegible]
0	.210	[illegible]	.125	[illegible]	[illegible]	[illegible]	-.038	.118	37	89	.188	-.036	[illegible]	35	85	[illegible]	-.030	[illegible]	33	[illegible]
1	[illegible]	-.038	.118	[illegible]	89	[illegible]	[illegible]	.111	35	84	.181	[illegible]	.107	33	81	.172	-.030	.101	32	76
2	[illegible]	[illegible]	.113	[illegible]	[illegible]	[illegible]	-.032	[illegible]	33	79	.170	[illegible]	[illegible]	32	76	.163	[illegible]	.096	30	[illegible]
3	[illegible]	[illegible]	.107	[illegible]	[illegible]	[illegible]	[illegible]	.101	32	76	.162	-.028	[illegible]	30	[illegible]	.155	-.026	[illegible]	28	68
4	[illegible]	-.030	[illegible]	[illegible]	[illegible]	.162	[illegible]	.094	30	71	.154	-.026	[illegible]	28	68	.148	-.025	.086	27	65
6	.154	[illegible]	[illegible]	28	67	.147	[illegible]	[illegible]	27	64	[illegible]	[illegible]	.082	26	62	.136	-.021	.078	25	59

Capacitance—The values in table for capacitance were derived by formulas in Alexander Russel's "Alternating Currents." These values are as follows:—C_1 values are the capacitance in microfarads per mile between one conductor and the other two conductors plus sheath. C_{1-2} values are the mutual capacitance in microfarads per mile between any two conductors. The capacitance to neutral is twice these values. C_{12} values per mile are used in the application of Russel's formulas for determining the capacitance corresponding to various arrangements of the three conductors and the sheath.

The Charging Current in amperes per mile for each conductor to neutral = susceptance in micromhos to neutral (taken from Table) × volts to neutral × 10^{-6}.

Dielectric Constant—All of the above table values are based upon a value for the dielectric constant K of 3.5. For all other values of K the table values will change in direct proportion. Values for K will usually be found between the following limits; for impregnated paper 3.0 to 4.0; for varnished cambric 4.0 to 6.0 and for rubber 4.0 to 9.0.

TABLE XXVIII—THREE-PHASE CHARGING KV-A PER MILE OF THREE-PHASE CIRCUIT OF THREE CONDUCTOR PAPER INSULATED CABLES

25 CYCLES

AREA IN CIRCULAR MILS	CHARGING KV-A PER MILE (EXPRESSED IN KV-A 3 PHASE) FOR PAPER INSULATED THREE CONDUCTOR CABLES BASED UPON A VALUE FOR 'K' OF 3.5 AND UPON A THICKNESS OF INSULATION SURROUNDING THE CONDUCTORS AND OF THE JACKET INDICATED									
	220 VOLTS	440 VOLTS	550 VOLTS	1100 VOLTS	2200 VOLTS	4400 VOLTS	6000 VOLTS		6600 VOLTS		6900 VOLTS
B & S NO.	4/64	4/64	4/64	5/64	6/64	[illegible]/64	10/64	14/64	10/64	14/64	10/64
500 000	.00600	.0240	.0376	.134	.488	1.66	2.76	2.26	3.35	[illegible]	3.66
450 000	.00575	.0230	.0360	.131	.469	1.62	2.66	2.22	3.22	[illegible]	[illegible]
400 000	.00550	.0220	.0346	.125	.455	1.58	2.58	2.15	[illegible]	[illegible]	[illegible]
350 000	.00545	.0218	.0342	.122	.440	1.51	2.51	2.08	[illegible]	[illegible]	[illegible]
300 000	.00532	.0213	.0333	[illegible]	.425	1.47	2.44	2.0	[illegible]	[illegible]	[illegible]
250 000	[illegible]	.0201	.0315	[illegible]	.406	1.39	2.33	.96	[illegible]	[illegible]	[illegible]
0000	.00483	.0193	.0303	[illegible]	.387	1.33	2.19	[illegible]	2.65	[illegible]	[illegible]
000	.00454	.0182	.0285	.099	.363	1.24	2.04	.72	2.49	2.09	[illegible]
00	.00424	.0170	.0266	.094	.343	[illegible]	1.90	[illegible]	2.31	[illegible]	[illegible]
0	.00400	[illegible]	.0250	.0883	[illegible]	1.08	1.79	1.5	[illegible]	1.83	[illegible]
1	.00376	[illegible]	.0236	.0836	.300	1.04	1.68	1.43	[illegible]	1.74	[illegible]
2	.00352	.0141	.0221	[illegible]	.286	.965	1.58	1.33	[illegible]	[illegible]	[illegible]
3	.00333	.0133	.0209	.0740	.261	.908	1.51	1.29	1.83	1.57	[illegible]
4	.00309	.0124	.0194	.0690	.252	.850	1.40	1.18	1.70	[illegible]	[illegible]
6	.00275	.0110	.0173	.0605	.218	.755	1.26	1.08	1.52	[illegible]	[illegible]

25 CYCLES

	10.000 VOLTS	11000 VOLTS		13.200 VOLTS		16 500 VOLTS	20.000 VOLTS		22.000 VOLTS	25000 VOLTS	
	12/64	12/64	14/64	12/64	16/64	14/64	16/64	18/64	18/64	18/64	20/64
500 000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	17.35	23.6	[illegible]	[illegible]	[illegible]	[illegible]
450 000	[illegible]	8.23	7.50	[illegible]	[illegible]	16.80	23.3	[illegible]	[illegible]	[illegible]	[illegible]
400 000	[illegible]	[illegible]	7.26	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	25.6	[illegible]	[illegible]
350 000	6.33	[illegible]	7.02	[illegible]	[illegible]	[illegible]	[illegible]	20.4	[illegible]	[illegible]	[illegible]
300 000	[illegible]	[illegible]	6.78	[illegible]	[illegible]	[illegible]	20.8	19.6	23.7	[illegible]	[illegible]
250 000	5.82	7.02	6.42	[illegible]	[illegible]	14.40	[illegible]	[illegible]	22.2	[illegible]	[illegible]
0000	5.53	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	17.6	[illegible]	27.6	[illegible]
000	[illegible]	[illegible]	5.82	[illegible]	[illegible]	13.05	17.6	[illegible]	20.3	26.3	[illegible]
00	[illegible]	[illegible]	5.45	[illegible]	7.30	[illegible]	[illegible]	[illegible]	[illegible]	24.4	[illegible]
0	[illegible]	[illegible]	[illegible]	9.00	[illegible]	[illegible]	[illegible]	4.8	[illegible]	[illegible]	22.0
1	[illegible]	[illegible]	4.84	7.48	[illegible]	[illegible]	14.8	4.0	[illegible]	21.9	20.7
2	[illegible]	[illegible]	4.48	7.13	6.26	[illegible]	14.4	3.2	[illegible]	[illegible]	20.1
3	3.82	4.60	4.36	6.60	[illegible]	[illegible]	[illegible]	12.8	15.5	20.1	18.8
4	3.62	4.36	4.00	[illegible]	[illegible]	[illegible]	12.8	12.0	[illegible]	[illegible]	17.6
6	3.22	[illegible]	3.63	[illegible]	[illegible]	[illegible]	[illegible]	10.8	[illegible]	[illegible]	16.3

60 CYCLES

	220 VOLTS	440 VOLTS	550 VOLTS	1100 VOLTS	2200 VOLTS	4400 VOLTS	6000 VOLTS		6600 VOLTS		6900 VOLTS
	4/64	4/64	4/64	5/64	6/64	8/64	10/64	14/64	10/64	14/64	10/64
500 000	.0143	.0574	.0900	.323	[illegible]	4.00	[illegible]	5.49	8.00	[illegible]	[illegible]
450 000	.0138	.0554	.0858	.313	1.13	3.88	6.40	5.33	[illegible]	6.48	[illegible]
400 000	.0132	.0530	.0830	.301	1.09	3.79	6.20	5.13	[illegible]	[illegible]	[illegible]
350 000	.0131	.0523	.0818	.292	1.05	[illegible]	5.98	[illegible]	[illegible]	[illegible]	7.93
300 000	.0127	.0510	.0798	.283	1.02	3.54	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
250 000	.0120	.0493	[illegible]	.270	.975	[illegible]	[illegible]	[illegible]	6.75	[illegible]	[illegible]
0000	.0115	.0463	.0725	.255	.925	3.22	5.24	4.33	[illegible]	5.26	[illegible]
000	.0109	.0437	.0685	.240	.870	3.00	4.88	4.12	5.92	[illegible]	[illegible]
00	.0102	.0410	.0643	.226	.820	2.80	[illegible]	3.84	5.52	[illegible]	6.03
0	.0096	.0385	.0602	.212	.768	2.61	4.30	3.59	5.22	4.35	5.70
1	.0090	.0362	.0566	.202	.720	2.48	4.08	3.44	4.95	4.17	5.42
2	.0084	.0339	.0530	.185	.680	2.34	3.80	3.19	4.60	3.87	5.04
3	.0080	.0320	.0500	.176	.632	2.18	3.59	[illegible]	4.35	[illegible]	4.75
4	.0074	.0296	.0465	.165	.600	2.05	3.37	2.87	4.08	3.48	[illegible]
6	.0066	.0265	.0415	.147	.522	1.82	3.05	2.62	3.70	[illegible]	[illegible]

60 CYCLES

	10.000 VOLTS	11.000 VOLTS		13.200 VOLTS		16.500 VOLTS	20.000 VOLTS		22.000 VOLTS	25000 VOLTS	
	12/64	12/64	14/64	12/64	16/64	14/64	16/64	18/64	18/64	18/64	20/64
500 000	16.7	20.1	18.5	28.9	24.9	[illegible]	[illegible]	[illegible]	[illegible]	83.3	[illegible]
450 000	16.5	19.8	18.1	28.5	24.4	40.3	[illegible]	[illegible]	62.7	[illegible]	[illegible]
400 000	15.8	19.0	17.3	27.2	23.5	35.5	54.0	[illegible]	[illegible]	[illegible]	[illegible]
350 000	15.3	18.4	16.8	26.4	22.4	37.6	51.6	[illegible]	58.3	[illegible]	72.2
300 000	14.6	17.6	16.1	25.2	21.8	36.0	50.0	46.8	56.5	[illegible]	[illegible]
250 000	13.9	16.7	15.4	24.0	20.5	[illegible]	47.3	44.3	53.6	[illegible]	[illegible]
0000	13.4	16.1	14.7	23.2	19.6	32.8	45.3	42.5	51.2	[illegible]	[illegible]
000	12.5	15.0	13.9	21.6	18.4	31.2	42.5	40.0	48.3	62.7	[illegible]
00	11.7	14.1	13.0	20.2	17.4	29.0	40.0	37.6	45.4	59.0	[illegible]
0	11.0	13.2	12.1	18.9	16.3	27.2	37.6	[illegible]	43.0	[illegible]	53.3
1	10.4	12.5	11.6	17.9	15.5	26.0	35.6	33.6	40.5	[illegible]	[illegible]
2	9.85	11.9	10.8	17.0	14.9	24.1	34.5	[illegible]	38.2	[illegible]	[illegible]
3	9.15	11.0	10.3	15.8	14.1	23.0	32.4	30.4	36.7	[illegible]	45.2
4	8.65	10.4	9.7	15.0	13.2	21.7	30.4	28.4	34.3	44.5	42.6
6	7.75	9.3	8.8	13.4	11.7	19.8	26.9	25.6	30.9	[illegible]	38.9

The values in Table XXVIII are based upon a value for the dielectric constant K of 3.5. For all other values of K the table values will change in direct proportion. Values for K will usually be found between the following limits; for impregnated paper 3.0 to 4.0; for varnished cambric 4.0 to 6.0 and for rubber 4.0 to 9.0.

$2\ C_1 + 2\ C_{12} = 0.410$ *mf. per mile* .... (78)

And $3\ C_1 + 6\ C_{12} = 0.450$ *mf. per mile* .... (79)

Therefore $C_1 = 0.26$ *mf. per mile*

$C_{12} = 0.055$ *mf. per mile*

Numerical Examples—From Table XXVII for a 250 000 circ. mil., three-conductor cable having a band of insulation surrounding each conductor of 16/64 of an inch and an insulation jacket surorunding all three conductors of the same thickness, the following values are obtained:—

$C_1 = 0.260$ *mf. per mile.*

$C_{12} = -0.055$ *mf. per mile.*

Then, in the order in which the capacitance increases,—

Capacitance between 1 and 2 = 0.157 mf. per mile.... (72)

Capacitance between 1 and 2, 3 = 0.210 mf. per mile.. (73)

Capacitance between 1 and S (2 and 3 insulated) = 0.230 mf. per mile .... (74)

Capacitance between 1 and S, 2 (3 insulated) = 0.248 mf. per mile .... (75)

Capacitance between 1 and S, 2, 3 = 0.260 mf. per mile .... (76)

Capacitance between S and 1, 2 (3 insluated) = 0.363 mf. per mile .... (77)

Capacitance between 1, S and 2, 3 = 0.410 mf. per mile .... (78)

Capacitance between S and 1, 2, 3 = 0.450 mf. per mile .... (79)

COMPARISON OF CALCULATED CAPACITANCE WITH TEST RESULTS

The difference between measured results of capacitance and the results calculated by the above formulas are given in Fig. 60. It will be seen that in all cases these calculated results are less than the corresponding test results, the discrepancy being greater as the conductor becomes larger and the separation less. The differences vary from zero to as much as eleven percent for the largest cable, at the minimum spacing shown. The discrepancy is greatest with the minimum thickness of insulation. Since such cables would be used only for low-voltage service, the charging current would be small and consequently this error would probably be of little importance. For 6600 volt cables the results by the formula would seem to be approximately five percent too low.

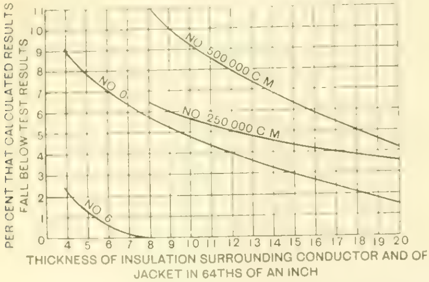

FIG. 60—COMPARISON OF CALCULATED AND MEASURED CAPACITANCES
Tests made on three conductor paper insulated cables, K = 3.5.

The cause of the discrepancy between the formula and test results is as follows:—In order to obtain a mathematical solution, Russell found it necessary to make certain approximations to the true physical conditions. Thus the resulting mathematical formula cannot give exact results. The approximation made by Russell is very close to the actual physical fact where the conductors are small compared with the insulation thickness, but it is not very close where the conductors are large compared with the insulation.

CHARGING KV-A—TABLE XXVIII

Table XXVIII contains values for charging current (expressed in kv-a, three-phase) for three-conductor paper insulated cables, both 25 and 60 cycles, based upon a value for *K* of 3.5. For other values of *K*, the table values would vary in proportion. For other thicknesses of insulation, the kv-a values would vary as the susceptance values corresponding to the thickness of insulation (See Table XXVII). In some cases, such for instance, as grounded neutral systems, the thickness of insulation of the jacket may be less than that surrounding the conductors. In such cases it might be desirable to calculate the susceptance and charging current, if accurate results were desired. The values for charging current corresponding to two thicknesses of insulation are included for some of the commonly employed transmission voltages.

These kv-a values were calculated by using the values for susceptance in Table XXVII which, in turn, were derived from the capacitance in the same table obtained by formulae (70) and (71). Thus a 350 000 circ. mil cable with 10/64 and 10/64 paper insulation has a 60 cycle susceptance to neutral of 167 micromhos per mile. Since the charging current in amperes to neutral equals the susceptance to neutral × volts to neutral × 10^{-6} and assuming 6600 volts, three-phase between conductors, we have:—

$$167 \times \frac{6600}{1.73} \times 10^{-6} = 0.637 \textit{ amperes to neutral.}$$

$$\textit{Charging kv-a} = 0.637 \times 3815 \times 3 = 7.25 \textit{ kv-a},$$

as indicated in Table XXVIII.

VALUES FOR K

The capacitance of any cable depends upon the dielectric constant of the insulating material and a dimension term or form factor. The dielectric constant should be determined from actual cables and not from samples of material. The usual range in value for *K* is given below.

	Value of K
Impregnated Paper	3.0 to 4.0
Varnish Cambric	4.0 to 6.0
Rubber	4.0 to 9.0

All values in Tables XXVII and XXVIII are based upon a value of *K* of 3.5. For all other values of *K* all table values will vary in the same proportion as their *K* values. The actual value of permittivity of most paper insulation runs about ten percent less than the value 3.5 which has been used in calculating the accompanying table values. The true alternating-current capacitance is always considerably lower than the capacitance measured with ballistic galvanometer.

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Application of Steam Condensers

Selection of Type

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CONDENSERS are very simple in construction, mechanically, and their principle of operation is not at all difficult to understand, but the application of condensers to secure the most economical operation is an entirely different matter. It is a problem depending on so many variables and susceptible of so many changes that many serious mistakes have been made. It is the purpose of this article to treat of the various factors bearing on the selection of the *type* of condenser. The discussion of the selection of the proper size of condenser is to be treated in a later issue.

THE SELECTION of the right condensers to serve steam driven prime movers is purely a question of power plant economics. The condenser, regardless of type, has no excuse for being in a modern power plant other than its reduction of the cost of power. Operating condensing, as compared with non-condensing operation, cuts the cost of power approximately in half. It is therefore essential that great care be exercised in making the selection, so that the full saving from condensing operation may be realized. The problem of condenser application thus reduces itself to a calculation to determine which equipment will produce power at the lowest cost.

Using the principle of operation as a basis of classification, there are two general classes of condensers; the surface type and the jet type. No attempt will be made to go into the details of design, but only to point out the fundamental principles that have a direct bearing on the selection. The surface condenser is a nest of tubes through which, or around which, cooling water is circulated. Steam is condensed on the surface of the tubes and collected in the hotwell, not being allowed to mix with the cooling water. In the jet condenser, the cooling water is introduced directly into the condensing chamber and mixes with the condensed steam. The distilled water is therefore not directly available for boiler feed, but if the cooling water is used for feed a portion of the warmed condenser discharge may be diverted for feed. This mixing of the water and condensed steam means one less pump for the jet condenser, as no separate pump is needed to handle the condensate. A variation of the jet type is the barometric or high level jet. In this type, the cooling water flows out of the condenser by the force of gravity, and under the most favorable conditions requires no circulating pump as the water is available within the suction lift of the vacuum in the condenser. Such installations are not numerous, however.

Every condenser must have some means of getting rid of the air and noncondensible vapors that collect in it. This may be accomplished with air pumps, with steam or water jet ejectors, or simply by depending on the entrainment of the air in the cooling water to carry it off.

To avoid confusion by introducing too many different kinds of condensers, this discussion is confined to the comparison of the surface and low level jet condensers, which represent the majority of installations. The same general methods would be applied in comparing any number of condensers with any of the numerous pump combinations that can be made.

In selecting the type of condenser to be used, the following points should be given consideration;—the space available, the boiler feed problem, the cooling water, maintenance and first cost. In most cases, by a general survey of these items, the selection can be made without resorting to refinements in calculations. If, however, such a survey discloses the fact that there is little difference, then each type of condenser should be taken up individually, determining the most economical size of each type, and then comparing these sizes, rather than the sizes that have been selected more or less arbitrarily. The general procedure in dealing with the factors of selection is to determine in each case the excess operating and installing costs involved with either type and, when these have been found, to summarize the whole, balancing one against the other. The excess operating and maintenance costs should be capitalized at a fair percentage and the resulting amount added to the condenser that has such an excess. This total is the amount that it is justifiable to pay in initial expense for the condenser that effects the saving.

SPACE REQUIRED

The amount of floor space and the head room available are rarely deciding factors in selecting condensers. Surface condensers require more floor space than jet condensers, especially when allowance is made for the space required to remove the tubes. In a new plant, space for a surface condenser can be arranged without difficulty, but frequently special turbine foundations have to be made to accommodate the condenser. The head room required in either case is about the same, with some adjustments possible by variations in design, such as the proportioning of the shell, or the use of twin units. On the whole, the question of space is not of primary importance, though the difference in the cost of the installation due to the space occupied, if any exists, should be reflected in the analysis for the selection.

BOILER FEED

Since the surface condenser recovers the condensate for boiler feed, whereas the jet does not, the quality of the water available for boiler feed plays a very important part in the problem of selection. There is practically no natural water that does not contain enough solid matter, either in suspension or solution, to form scale in boilers. Some waters contain minerals that form a hard scale, while others, with just as high a content of minerals, form a soft brittle scale easily removable. The question of treating feed water, what minerals are most objectionable and methods of cleaning boilers cannot be discussed here, but most feed waters have to be treated. The methods of securing good feed water vary from a chemical treatment of all of the feed to the recovery of the condensate with a surface condenser, and treating only the make-up water.

Although the surface condenser should deliver pure distilled water to the feed heater, this is not always the case. The purity of the water depends on the tightness of the tube packing and the condition of the tubes themselves, because if the tubes leak the feed water will be adulterated by the amount of the leakage. For this reason frequent electrical or chemical tests of the condensate to determine its quality should be made.

FIG. 1—5000 SQ. FT. SURFACE CONDENSER FOR 5000 KW DOUBLE-FLOW TURBINE

With surface condensers in a plant probably not more than 90 to 93 percent of the boiler feed will be returned to the boilers and the rest will have to be made up. This make-up water will have to be treated, but the expense of treating is small compared to the expense of treating incurred with jets, where all the feed must be treated. There will also be a loss of heat in the feed when jets are used unless the feed is taken from the discharge of the condenser, because the temperature in the hotwell of a surface condenser is higher than the temperature of the cooling water.

When investigating the feed water phase of the problem it will therefore be necessary to find out the excess cost of treating the feed, the amount chargeable to the jet for the loss of heat in the feed, and the excess cost of the treating plant. The cost of treating is variable, depending on the nature of the water to be treated, but ordinarily the cost does not exceed fifteen cents per thousand gallons. The loss of heat can be reduced to the amount of steam required to bring the temperature of the feed to that of the condensate in a surface condenser, and then find the cost of generating this steam. The cost of a treating plant will depend on the method used and the amount of water to be treated. With all these items determined another step in the analysis is completed.

COOLING WATER

Of almost equal importance as the boiler feed is the cooling water problem, the quality, quantity and cost of handling. A condensing plant requires from 25 to 100 pounds of water per pound of steam condensed for condensing water alone. It is quite desirable to secure a plentiful supply of water at a low temperature, and at such elevations as to require a minimum pumping power. Natural heads are desirable but not often available for steam plants. Where the water supply is limited, an artificial cooling system can be installed, and the amount of water circulated will then depend on the cooling range that can be effected by the cooling system and not on the type of condenser employed.

Cooling towers and spray ponds are both used for artificial cooling. The rise in the temperature of the cooling water must be kept within the cooling range of the tower or pond, since the water has to be cooled just as much as it has been heated in passing through the condenser. For the average conditions of temperature and humidity, say 70 degrees air temperature and 70 percent humidity, the cooling range for a natural draft tower or a spray pond, single spraying, is usually assumed to be from 14 to 16 degrees and, for a forced draft tower or a pond with double spraying system, from 22 to 25 degrees. This means that the ratio of water to steam would be between 60 and 70 to 1 in the first case and about 40 to 1 in the latter.

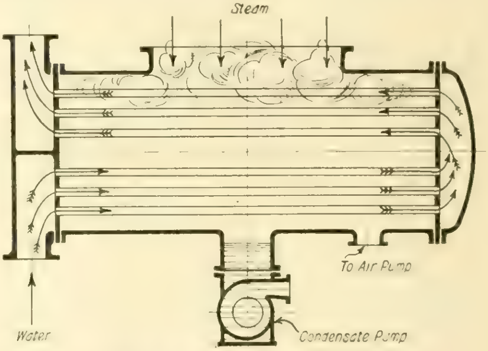

FIG. 2—DIAGRAM OF ELEMENTARY SURFACE CONDENSER

The effects of bad water on jet condensers are of less moment than with the surface condenser, as the parts subject to corrosion can be replaced more cheaply. The tubes in a surface condenser will last indefinitely, if the water is noncorrosive, but, with such water, surface condensers are not ordinarily used. When the water is quite bad, the tubes last only a short time and although it may be highly desirable to save the condensate, the cost of doing this may not compare favorably with the cost of boiler feed from some other source.

By far the most important phase of the cooling water problem is the cost of handling the water under the conditions that may exist in the power plant. The jet, by reason of its ability to realize a lower terminal difference than a standard surface type, i. e. difference between the temperature of the exhaust steam and that of the outgoing cooling water, does not require as much water under average conditions as the surface condenser. This, however, does not mean that it will require less power. The jet has to pump all the water out of the vacuum corresponding to about 30 feet suction lift and, in addition, has to discharge against an external discharge head that is never less than the external discharge head on the surface condenser. The external head consists of the static lift plus pipe friction. This means that the jet always has a pumping head above thirty feet, whereas the surface condenser may not require a greater head than condenser and pipe friction. Such a case would exist where the water is taken from a lake or a river and discharged back to the same level, the whole system being sealed so that the full syphonic effect is realized. Such installations are quite frequent. With a discharge level above the basement floor, such as is usually encountered in spray pond and cooling tower installations, the advantage of a lower pumping head is also with the surface condenser because it can take advantage of the balanced leg in the circulating system, while the jet cannot. As an example, assume a cooling tower installation with the level of the cold well ten feet above the basement floor. There will be a ten foot positive head on the circulator of the surface condenser and this ten feet can be credited because, under static conditions, the level of the water in the system would be that far above the floor, but the jet cannot take advantage of this head because it will have to pump the water ten feet in addition to the internal head due to the vacuum. From this it is evident that in most cases the advantage of head lies with the surface type.

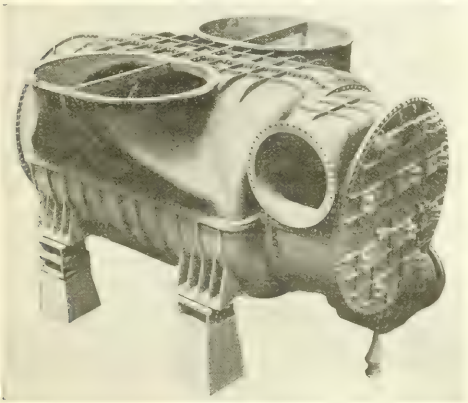

FIG. 3—45 000 SQ. FT. SURFACE CONDENSER SERVING A 25 000 KW DOUBLE-FLOW TURBINE

Since with a surface condenser, the vacuum obtainable depends on a variety of things, including the rate of heat transmission through the tubes, the velocity of the circulating water, and the size of the condenser, it is possible to select a number of condensers, each with a different ratio of water circulated to the square feet of surface, that will give approximately the same vacuum with a given amount of steam. But, with the jet condenser the number of gallons of water is practically fixed when the quantity of steam and vacuum are determined. This is due to the fact that most jets realize a terminal difference between five and eight degrees, indicating that the rise in the temperature of the circulating water and the ratio of water to steam will be practically the same for all jet condensers giving a certain performance. Thus with a surface type the ratio of water to surface can be varied to suit the conditions of pumping heads and the necessity for conservation of the auxiliary power. It is generally recognized that, for high heads, there should be a lower ratio of water to surface than for low heads. This permits of a reduction of the quantity of water to be pumped, cutting down the auxiliary power and operating expense at the cost of a greater initial investment for a larger condenser. No such manipulation is possible with the jet, but since its ratio of water to steam is lower in practically every case, it has a chance to approach the surface condenser in pumping power as the heads increase, overcoming the handicap of having to pump against a greater total pumping head by its decreased amount of water to be pumped.

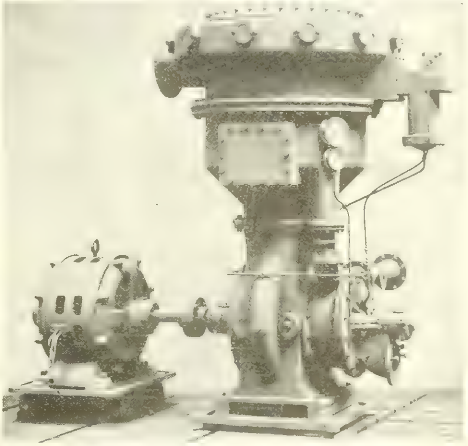

FIG. 4—SMALL MOTOR-DRIVEN JET CONDENSER FOR 500 KW TURBINE

The comparison of the power requirements is not determined alone by the comparison of the quantities of water circulated and the heads existing, but also by the fact that the jet condenser discharge pump is inherently less efficient than a pump not discharging from a vacuum, and that the jet must have a larger air pump than the surface. Against all these handicaps of less efficient pumps, greater heads and more power for the air pump, the jet has the advantage of less water to circulate. In most installations, the jet requires more power for drive, the amount of this excess depending on the discharge head, the type and capacity of the air pump, and the vacuum at which the condensers are compared. With this excess determined, an excess charge in operating expense can be made. This should be taken at a fair rate per horse-power-hour for the total number of hours per year the condenser will be in service, thus giving another item for the final comparison.

CONDENSER DRIVES

The type of drive, whether electric or steam, depends entirely on the use that can be made of the exhaust steam. If other steam-driven auxiliaries, such as drives for stokers, fans and boiler feed pumps, furnish enough exhaust steam to heat the feed water, it will not be necessary to have the condenser auxiliaries steam driven. In accounting for the excess power on steam drives, it is customary to neglect a charge if all the steam can be used to an advantage in heating. If motor driven, the charge is usually determined by taking the water rate on the turbine from which the motor derives its power, allowing for all electrical losses, thus arriving at the equivalent steam consumption per horse-power of the motor load. In most plants this will run from fifteen to twenty pounds per horse-power-hour. The charge for excess power can then be found from the cost of producing the excess steam that is required.

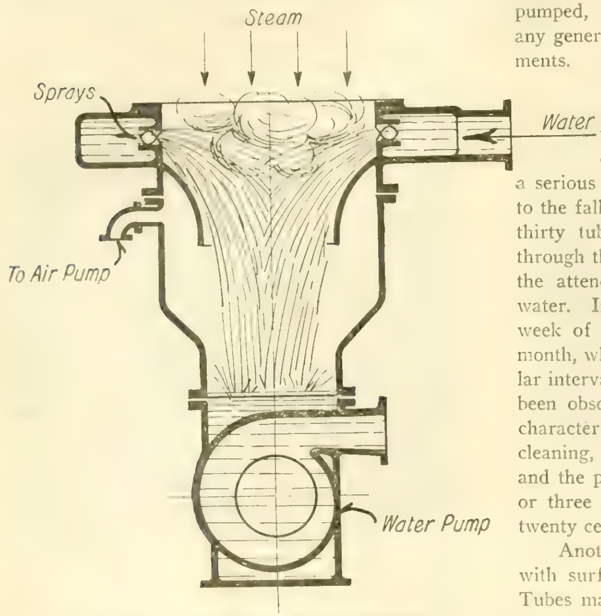

FIG. 5—DIAGRAM OF ELEMENTARY JET CONDENSER

FIRST COST AND MAINTENANCE

In the matter of first cost the jet has quite a decided advantage as it usually costs about half as much as the surface condenser. A jet condenser for a 10 000 kw turbine will cost about $30 000 delivered and erected at the present prices, and a surface condenser for the same turbine will cost about $65 000. It is this great difference in first cost that often makes the installation of the jet justifiable, for such a wide difference will offset a considerable amount of capitalized savings.

Since the jet condenser has only two pumps, whereas the surface has three, the cost of keeping the pumps of a jet in repair will not be as high as for the surface, but the difference is so slight that it can be neglected without any very great inaccuracy. Pump runners may last anywhere from a few months to several years, depending on the kind of water being pumped, so that it is almost impossible to give any general data on the cost of making runner replacements.

As to cleaning, the jet requires practically no attention, often going for years without being opened, but a surface condenser must be cleaned frequently to prevent a serious loss of vacuum. The loss of vacuum is due to the falling off of the rate of heat transfer due to the thirty tubes and a restriction in the flow of water through the condenser. The frequency of cleaning and the attendant cost vary with quality of the cooling water. In some plants condensers are cleaned after a week of service, in others they are allowed to go a month, while in others they are not cleaned at any regular intervals but only after a definite loss in vacuum has been observed. The cost of cleaning varies with the character of the deposit on the tube, the method of cleaning, facilities for handling the water box covers, and the price of labor. This cost may vary from two or three cents per square foot per year to fifteen or twenty cents per square foot.

Another important item of expense, in connection with surface condensers, is the replacement of tubes. Tubes may last several years or they may last only a few months, depending on the composition of the tubes and the character of the water. There are cases on record where tubes have lasted for fifteen years but this is exceptional. Most operators around manufacturing sites, where the water is liable to be contaminated with sewage and refuse from industrial plants, are glad to get five or six years average life out of their tubes. Some plants do not average more than a year. Here again the limits are so wide that general figures would be misleading. At the present price of tubes and a five year life it would cost about 18 cents per square foot per year for tubes alone, not taking into consideration extra ferrules and packings, and the cost of installation. These latter items would increase this figure to at least 30 cents per square foot for replacements.

SUMMARY

After having investigated the cost of boiler feed, the charge for excess power for auxiliaries, the difference in first cost and maintenance, and any other items of expense connected with the installation or operation of the condensers, it is possible to compare the types on a capitalized savings basis to determine which is the most economical to install. The savings in operating expense capitalized at the proper percentage will give the additional amount that can be justified to spend on initial expense to accomplish this saving.

To illustrate the method of procedure, assume that the problem is to decide between a surface and a jet condenser for a 10 000 kw plant, under the following conditions: 200 lbs. steam pressure, 100 degrees superheat; space no consideration; boiler feed treating costs 12 cents per 1000 gallons, including chemicals and attendance; abundant cooling water, available at a head of 10 ft., external to the condenser; surface condenser maintenance including cleaning and replacing tubes, 35 cents per sq. ft. per year; maintenance on pumps, the same in either case; plant operating 7000 hours per year at an average condensing load of 100 000 pound per hour; condensers to be selected on the basis of 75 degree water and 28.25 inches vacuum; condenser pumps to be motor driven because no exhaust steam needed for heating the feed water.

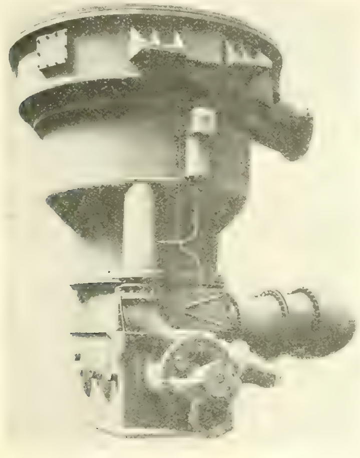

FIG. 6—LARGE JET CONDENSER

Circulating 13 000 gallons per minute to serve a 15 000 kw turbine.

First, in selecting the sizes of condensers, it will take a jet condenser circulating 12 000 gallons per minute, and a surface condenser of 15 000 sq. ft. of surface circulating 17 500 gallons per minute to give the required performance. The ratio of water to surface for the surface condenser has been taken in accordance with common practice for this low head condition. The jet will require 340 horse-power for drive and the surface will require 230 horse-power. The water rate on the main turbine is about 10 lbs. per brake horse-power and, assuming that the motors will receive their power from the main unit at an overall transmission efficiency of 82 percent, including generator, motor, transformer and line losses, the steam per horse-power-hour chargeable against the pumps will be 10 ÷ 0.82 or 12.2 lbs. per hour. It has been assumed that the steam will cost 35 cents per 1000 lbs. to generate, and the motor driven pumps are charged on this basis.

For this plant it is assumed that if a jet condenser were used, that the water for boiler feed would be taken from the discharge side of the condenser taking advantage of the higher temperature. When condensing 100 000 lbs. of steam per hour the condenser chosen will have a discharge temperature of 91 degrees and the hotwell temperature of the surface condenser would be about 92 degrees. There is such a slight difference in these temperatures that the heat lost in the feed when using a jet as compared to the surface may be disregarded without serious error.

TABLE I—COMPARISON OF SURFACE AND JET CONDENSERS

Items	Surface	Jet
Cost of boiler feed per year.......	$ 785	$ 9,800
Cost of power for pumps	6,875	10,160
Maintenance, surface	5,250	. . . .
Pump maintenance, same	......	......
Totals	$12,910	$19,960
Saving in favor of surface	$ 7,050	......
Capitalized against jet @ 15%	.....	47,000
First cost of condenser	65,000	30,000
Cost of water treating plant	2,000	15,000
Totals	$67,000	$92,000

The results of the comparison are given in Table I. From this it is evident that the surface condenser has the advantage over the jet because, based on the saving effected by the surface, we could afford to pay $92 000 for it with the water treating equipment, whereas it costs only $67 000. This conclusion could also have been reached by calculating net savings instead of capitalized savings but the latter is usually found preferable since it indicates directly whether the prices asked for the equipment are justifiable. The condensers used in this comparison were selected on the basis of common practice.

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

DECEMBER 1920

Checking Armature and Axle Bearing Wear

The proper maintenance of motor bearings, involves careful inspection and gauging to determine when renewals should be made in order to keep the motors in good operating condition. This is most important in connection with armature bearings, for when these are neglected and allowed to wear down too far, the armature will rub on the poles and may cause the destruction of the armature winding and more or less damage to the fields.

BEARING WEAR

In the case of motors mounted on cars equipped for single-end operation running in one direction only, the bearing wear due to the torque of the motor and the action of the gear and pinion, depends on the rotation of the armature, as is shown in Table I, which applies to either double or quadruple equipments of right hand motors.* With cars running in both directions, wear on both the armature and axle bearings is more uniformly divided between the top and bottom.

TABLE I—DIRECTION OF BEARING WEAR

Position No.	Inside Hung Motors			Outside Hung Motors		
	Armature Rotation	Bearing Wear		Armature Rotation	Bearing Wear	
		Armature	Axle		Armature	Axle
1 and 3	Left	Down	Down	Right	Up	Up
2 and 4	Right	Up	Up	Left	Down	Down

INITIAL BEARING ALLOWANCES

Depending upon the size of bearings for either the armature or axle, they are given an initial clearance when new or re-babbitted as shown in Table II.

MOTOR AIR-GAPS

As it is common practice to check the armature bearing wear by measuring the air-gap of the motor, the range of air-gaps in railway motors is given in Table III, the single air-gap being expressed in common fractions, 64ths and decimals for greater convenience. The single air-gap minus half the initial clearance represents the amount of wear which may take place before the armature rubs on the field poles.

TABLE II INITIAL CLEARANCES

Size of Shaft or Journal	Maximum	Minimum
From 2¼ up to 3 in.	0.008	0.006
From 3 up to 3¼ in.	0.010	0.008
From 3¼ up to 3¾ in.	0.012	0.010
From 3¾ up to 4¼ in.	0.014	0.012
From 4¼ up to 6 in.	0.016	0.014
From 6 up to and including 7 in.	0.018	0.016

ALLOWABLE SAFE WEAR

It can be seen from Tables II and III that the allowable wear in bearings can vary considerably on different motors before the armatures will rub on the poles and in general is less on smaller machines than on the larger size ones. It is not desirable, however, to allow too great bearing wear, especially on the larger motors. It is considered a safe working rule to replace bearings after they have worn approximately $\frac{1}{16}$ to $\frac{3}{32}$ in., for with this wear added to the initial clearance allowed on the new bearings, there is considerable pounding of the armature which tends to increase the bearing wear rapidly to the danger point.

TABLE III—RAILWAY MOTOR AIR-GAPS

Total Air-Gap	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Single Air-Gap	0.075	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Single Air-Gap	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Single Air-Gap	[illegible]	0.093	0.125	0.140	[illegible]	[illegible]	0.187	[illegible]	0.234	[illegible]

CHECKING BEARING WEAR

The following methods are used to determine when bearings are worn to the limit and should be replaced.

Light Test—This test is applicable to motor frames that have inspection holes so located that a light can be held at one end of the motor and clearance in the air-gap observed by the workman. This method depends largely upon the judgment and experience of the man making the inspection and cannot entirely be relied upon.

Sweep Gauge on Under Side—This method, very commonly used by many operators, requires a sweep gauge made of varying thicknesses of card board or soft metal, and sometimes a long narrow flexible steel strip fitted with steel pads of varying thicknesses. These gauges are inserted in the air-gap at the lower side of the motor. When the limiting minimum gauge cannot be entered, the bearings show maximum allowable wear and should be renewed. In general, this method requires that the lower commutator cover be removed in order to apply the gauge.

Sweep Gauge on Upper Side—This method requires a similar type of gauge as used above, except that when the maximum gauge can be entered in the air-gap at the top side of the motor, the bearings show maximum allowable wear and should be renewed. Using this method, gauges are inserted in the top commutator opening, the cover of which can readily be removed for this inspection.

Lifting Armature Manually—On very small armatures the bearing wear can be approximately obtained at the commutator end by reaching in through the top commutator opening, lifting the armature and noting the play. This is a crude method and is only used to get a rough approximation of the wear. If play is noticeable, the lower commutator cover is removed and a sweep gauge used to check the air-gap. A more reliable test, similar to the above, is made by removing the lower half of the gear case and prying up the armature at the pinion and measuring the lift from a fixed point on the motor frame or the gear. This scheme gives actual pinion end bearing wear and is satisfactory, but involves considerable labor and time.

Lifting Armature by Motor Power—The following method, used successfully by a number of operators, requires the use of a minimum size sweep gauge, which is entered into the air-gap of the motor and, with the brakes set, power is applied, using the first notch of the control only. If the gauge shows clearance under these conditions, the bearings are considered O. K. This test must be made with the reverser on the car thrown in both forward and reverse positions in order to check all the motors.

Feeler Gauge—When the motor is off the car and the pinion is removed, the pinion end bearing wear can be measured with a feeler gauge. This method is accurate but not practical, as it requires too much work to check the bearings under these conditions. This method can be used to check the commutator end bearing of a motor on the car by removing the commutator end dust cap. With experience, the condition of the pinion end bearing can be estimated from the wear on the commutator end.

Special Methods and Apparatus—One operator reports considerable success in determining maximum allowable bearing wear by building up the front core band with solder and turning this down so that it extends $\frac{1}{16}$ inch above the armature iron. When this band begins to show signs of rubbing on the poles it is an indication that the bearings should be renewed. Three or more pads of solder built up $\frac{1}{16}$ inch above the band and spaced equally around the armature would give a similar indication.

A device has been patented and used by one operator which is arranged so that when the bearings wear down to a predetermined point, contact is made between the laminations of the armature and a small brass wheel supported by the frame. This wheel is caused to rotate and make contact with a bare fused jumper between the field coils, which grounds this field

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*Nomenclature—**A Right Hand Railway Motor** is one that has the axle bearing to the right when facing the commutator end of the motor. All modern motors and a large percentage of the older type motors are right hand.

Right Hand or Clockwise Rotation occurs when an armature turns in a clockwise direction to an observer facing the commutator end of the motor.

jumper, burning the fuse off and opening the motor circuit.*

AXLE BEARINGS

Excessive wear of axle bearings is not so serious, as it only subjects the frame, axle cap and axle cap bolts to increased shocks and strains, and tends to spread the gear centers, with resulting less efficient gear operation, and rapid wear. For the above reasons, it is considered good practice to renew axle bearings that show a wear of from ⅛ to $\frac{3}{16}$ inch. This is especially true with motors using 4 or 4¼ diametral pitch gears.

Checking Axle Bearing Wear—This wear can readily be checked with a feeler gauge by the workman from the pit, if the motors are not fitted with axle shields. Where shields are used and are fitted with inspection holes, the bearing wear can be checked through these openings. If inspection holes are not provided in the axle shield, it is necessary to remove them to make the inspection.

Another method is similar to that explained in checking armature bearing wear, by setting the brakes and throwing the control to the first notch and noting the play of the bearing by the lift of the motor frame. To check all motors on a car requires that this test be made for both forward and reverse positions of the reverser.

John S. Dean

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*This apparatus is described in the **Electric Railway Journal** for May 17, 1919, p. 971.

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

To receive prompt attention a self-addressed, stamped envelope should accompany each query. All data necessary for a complete understanding of the problem should be furnished. A personal reply is mailed to each questioner as soon as the necessary information is available; however, as each queston is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply.

1921—COMPUTING MACHINERY FOUNDATIONS—Referring to the JOURNAL for Sept. 1920, p. 391, under the heading "Anchorage," it is stated that if a plain round bar were used, the required depth would be:—

$$\frac{\text{working strength}}{\text{bond of concrete}} = \frac{10\,000}{80} = 138 \text{ in}$$

The writer questions the above value of 138 inches. Please refer to the series of articles on Foundation Anchor Bolts for Engines and Machinery which were published in *Practical Engineer* on the following dates:-Aug. 1st, 1915; Aug. 15th, 1915; Sept., 1, 1915; Sept. 15th, 1915; Oct. 1, 1915; Dec. 1st, 1915; and Jan. 15th, 1916. T.C. (MO.)

The example in question should read

$$\frac{\textit{working strength}}{\textit{bond of concrete}} = \frac{11\,000}{80 \times 1\frac{1}{8}\pi} = 39 \textit{ in.}$$

and the following example—

$$\frac{11\,000}{100 \times 1\frac{1}{8}\pi} = 31 \textit{ inches.}$$

The above was an error in transcription from the original manuscript and the writer wishes to thank the questioner for raising the point. A.H.C.

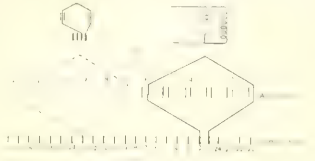
1922—SHUNT AND SERIES FIELD WINDINGS—(a) What are the formulas and methods of calculating the change of the series fields to shunt fields for a direct-current series motor. The power, voltage and speed are to remain the same. What relation do the size of the wire, number of turns and the outside dimensions for the shunt field coils have with the horse-power, voltage, full-load current, and full-load speed. All dimensions of the series field coil, the maximum dimensions for shut field coil can be obtained, in fact any data required from the motor can be had if necessary. What would the speed of a series motor, separately excited, drawing the rated full-load current at normal voltage, be compared with the speed of same motor self excited and working under the same conditions. Can the speed of a series motor be calculated when the horse-power, voltage and full-load current are known without connecting the motor up to a load? A.J.V.A. (CAL.)

As we understand this question it is desired to change a motor now having a series field to a shunt wound machine. In a given machine the field strength is determined by the number of ampere-turns in the field windings, i.e. the product of the amperes flowing in the field circuit and number of turns through which this current flows. With a given series machine at a given load the current is known and the number of turns per coil can be determined by dismantling the coil. To obtain a shunt machine of the same speed at the given load it will be necessary to change the field coils so that they will contain approximately the same number of pounds of wire but will be of sufficient resistance to permit being connected directly aoross the line. This means increasing the number of turns and decreasing the size of wire, so that the resulting resistance of the field coil will be such that the line voltage will cause a current to flow which, multiplied by the number of turns used, will give the same ampere-turns as the original machine at the given load. This condition must be obtained with a combination that will also give approximately the same weight of wire as the original coils to prevent overheating. Neglecting the somewhat larger space required by the insulation on the smaller size wire of the shunt coil, it should be approximately the same size as the original series coil. The speed of a series motor, separately excited, drawing rated full-load current at normal voltage would be fairly close to the same as the speed of the same motor self excited and working under the same conditions. The only difference would be due to the separately excited motor having line voltage across the armature while the self excited series motor would have somewhat less than line voltage across the armature due to the voltage drop in the series field. Of course, the separately excited motor would have shunt characteristics, provided the field current remains constant. Knowing the horse-power, voltage and full load current of a series motor the speed could not be calculated without knowing practically all of the detail dimensions of the machine as well as the field and armature windings. G.H.G.

1924—AUTO-LITE THIRD BRUSH GENERATOR—I have a small six volt, direct-current generator, Auto-lite third brush regulation, which was entirely rewound. Armature is lap wound with a pitch of 6, 12 slots, 24 commutator segments, turns 11, wire No. 18, lead 4, left top, lap wound, 2 pole, field coils have 330 turns of No. 20 wire per coil.

I tried the machine separately excited and while there was a strong field of correct polarity, when armature was driven, there was no current at the brushes and even by moving the brushes we could get no readings but the armature heated up considerably. Can you give me any explanation of this. Would not the cause of armature heating be the current circulating through it and if so why did we not get any indications at brushes? G.T.K. (ALBERTA)

Evidently you are commutating the coils when in the maximum field instead of when in the neutral position as shown in Fig. (b). This would result in a heavy current when the coil was short circuited by the brush but would not show any thing in the outside circuit.



FIGS. 1924 (a) and (b)

If the armature is correctly connected in this way it may be that running it in the opposite direction of rotation will cause it to "pick up." If this proves to be the cause, the leads to commutator will have to be reversed as shown in dotted lines at the left of Fig. (b). The commutator bar should not be opposite slot in which coil lies as shown in Fig. (a). A.M.D.

1925—ARRANGEMENT OF TWO-PHASE WIRES IN IRON CONDUIT—On a two-phase, four-wire system, must the four wires be placed in one conduit or can each phase *A* and *C* be placed in one conduit and the other *B* and *D* be placed in another conduit. I have two 3.5 inch conduits running through a brick wall from the transformer vault to the main switchboard and want to put four 500 000 circ. mil wires in each pipe and by splitting the phases in the two pipes I can make a better looking job but I do not know whether this will cause induction and excessive heating. *A* and *C* are one phase. *B* and *D* are another phase and I wish to place *A* and *C* in one pipe and *B* and *D* in the other pipe and connect the four wires to one switch. Then I wish to arrange the other four wires the same way and connect them to another switch. O.F.A. (OHIO)

If there is no physical connection between the two phases it will be entirely satisfactory to place the cables from one phase in one conduit and those from the other phase in the other conduit.

It would not be satisfactory to place the outgoing leads from both phases in one conduit and the return leads from both phases in the other conduit.. The whole idea is to have the sum of the currents in any conduit zero at any instant, which is met by the conditions outlined above. These same conditions require that in a three-phase circuit all of the conductors should be enclosed in the same conduit, as this is the only way that the algebraic sum of the currents is zero at all times. C.R.R.

1926—**CHANGING TRANSFORMER FREQUENCY**—What effect will using a 25 cycle power transformer on a 60 cycle circuit have on the capacity of transformer? What will be the changes in their losses, also any other effect that may be expected in making this change. The transformers in question are three 750 kv-a and three 335 kv-a, single-phase 33 000 to 440 volts, delta connected. J.S, (MO.)

Changing the frequency of a circuit effects the iron loss of the transformer considerably, but has little or no effect on the copper loss. The effect of a change in frequency on iron loss is discussed in detail in articles by Mr. E. G. Reed published in the JOURNAL for 1917, p. 357, and November 1917, p. 475. This relationship is somewhat complicated but in general it may be stated that the iron loss at 60 cycles will be in the neighborhood of one-half the loss at 25 cycles. This decreased loss will permit increased load on the transformer without exceeding the same maximum temperature. The extent of the increased load will depend upon the ratio of iron loss to copper loss in your particular transformers, and can best be determined by experiment. In general the iron loss is much smaller than the copper loss at full load. C.R.R.

1927—**ARRANGEMENT OF CABLES IN CONDUIT**—Fig. (a) shows a digram of connections (alternating-current side, only) of a 240 hp. synchronous motor. If this method of wiring is used, is it going to cause noise, heating of conduits and conductors? A rotary converter is to be wired in the same way. Two 2.5 inch conduits are run from each transformer, (each conduit containing three 4/0 conductors,) to the switch board. From the switch board to the converter there will be three 2.5 inch conduits, each containing 4/0 conductors. Is this going to cause trouble? How is the alternating-current voltage of 187.5 (input) determined in a 6 phase rotary converter of 250 volts direct current, which is fed from three delta connected, single-phase transformers? B.R. (OHIO)

The arrangement of cables and connections shown in Fig. a will be satisfactory, and no trouble should be experienced from noise, heating of conduits or conductors or losses above the normal I^2R losses of the cable, providing all conductors are approximately of the same length, so that the resistances are nearly equal. In connecting the converter, the same method should be followed, i.e., a balanced, three-phase grouping for each conduit. From the data given we do not see how the converter is to be connected from the switchboard, as there are three conduits of three 4/0 cables each, making a total of nine cables. Since the converter is six-phase, there will be six leads from the converter to the switchboard. The rating of 187.5 volts alternating-current represents the open circuit voltage of the transformers. The difference between this and the theoretical voltage, (0.707 times direct-current volts), is to compensate for the regulation in the transformers, leads and converter so that the rated direct-current voltage is obtainable at full load on the converter. W.F.D.

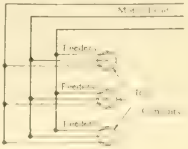


FIG. 1927 (a)

1928—**WATTHOUR METERS FOR FORWARD AND REVERSED POWER**—Some times the town in which our factory is located requires extra power which is supplied from our factory plant, and at other times the factory obtains power from the town plant through the same lines. Is there any meter that will operate in both directions so that it would register in one direction when they are getting power from us and in the other direction when we are getting power from them, one registration being automatically deducted from the other so that at the end of the month we would have plus or minus registration indicating the amount of power for which we owe them or they owe us? J.A.A. (N.B.)

Any watthour meter will register backwards when the power is passing through it in the reversed direction and will run the dial train backward at practically the same rate as if the power were being registered in the normal direction. The only difference is that produced by the light-load adjustment. For the same load the meter will register less when running backward than when running forward by twice the amount of this light-load adjustment. This light-load adjustment is so small, however, as to be practically neglible for anything like full-load in either direction. Any commercial watthour meter will be satisfactory for the purpose you indicate. We would recommend, however, that a polyphase meter be used for polyphase load, as the registration of two single-phase meters is apt to be quite confusing if the power-factor should be below 50 percent. If you are not willing to neglect the amount of this light-load adjustment or if you desire to register the total amount of power that is passing in each direction, it is customary to put in two meters, so connected to register the power in each direction, and then mount a small ratchet on each meter shaft which will prevent it from rotating backwards. This ratchet must be so designed that the friction introduced will be practically negligible or else additional compensation must be introduced into the meter element to overcome the increased friction. Such meters will register the total amount of power that passes in each direction and the difference between the registrations will, of course, indicate the amount which is due one company from the other. C.R.R.

1929—**RING FIRE**—We have a compound wound, direct-current generator with commutating poles, capacity 300 kw, 245 volts, 750 r.p.m., driven by a synchronous motor. As the voltage is built up, at about 100 volts a faint ring of fire completely circles the commutator and always under the last brush at the bearing end of the commutator. This ring grows in intensity until about 150 volts are indicated when it begins to diminish and gradually dies out altogether at 200 volts. After that commutation is perfect. On shutting down the machine the same result occurs. Very often this ring snaps with quite a loud noise. Can you suggest a remedy for this trouble? C.P. (ONT.)

This is a problem of "ring-fire" instead of commutation, and has little or nothing to do with the commutating characteristics of the machine. This ring-fire is usually due to carbon or graphite from the brushes, with possibly a trace of oil, which adheres to the mica between commutator bars. It is the incandescence of this material which gives the ring-fire. This incandescence is a function of the voltage between bars and the duration of such voltage, for it takes a perceptible time to attain the incandescent stage. The voltage between bars is practically zero in the neighborhood of the brushes, rises to a maximum about midway between brushes under no-load conditions, and then falls to zero under the next adjacent brush. The degree of incandescence will, therefore, depend both upon voltage between bars and the time in passing from one brush to the next. If the above trouble occurs when the machine is being brought up to speed, then the tendency toward ring-fire rises as the voltage increases, but decreases as the speed increases because of the shorter period of voltage between bars and better radiation of heat due to increased windage. Apparently, therefore, in this particular case, the tendency to decrease the ring-fire with increase in speed about balances the effect of increase in voltage, at about 150 volts. Beyond this, the effect of the higher speed counteracts that of the increased voltage. At less than 100 volts, incandescence apparently does not show, due to the too low voltage. As a rule, this ring-fire is not at all harmful, especially in a case like the above. However, if there is considerable oil on the commutator and this oil penetrates the mica between bars, then ring-fire eventually may "pit", or eat away, the mica in spots. For this reason the free use of lubricating oil on commutators is not recommended in modern practice. If a lubricant is needed on the commutator, some type of self-lubricating brushes should be used. If such brushes have considerable graphite as a lubricant, such graphite, rubbing off on the mica, may produce ring-fire, but this is only a surface effect and is not as liable to produce pitting as when oil is present. B.G.L.

1930—POLE PITCH—What normally determines the pole pitch of an induction motor? G.J.W. (CAL.)

The pole pitch is the distance between centers of adjacent north and south poles. It is very often expressed in inches measured on the bore periphery. However, in its relation to the windings, the pitch is generally expressed in number of slots. Assuming a machine which has 72 equidistant slots and eight poles, the pole pitch would be 72 divided by 8 or 9 slots. When the coil spans exactly the distance between the centers of adjacent poles, as it does when placed in slots 1 or 10, it is said to be a full pitch coil or winding. Such a coil would span 180 electrical degrees. In a chorded winding the coils have a fractional pitch and their span is less than the distance between centers of adjacent poles. Suppose the coil is placed in slots 1 and 8 instead of 1 and 10 it would then span 140 electrical degrees as each slot represents 20 degrees. Chorded windings having fractional pitch are described in an article on Reconnecting Induction Motors by A. M. Dudley in the JOURNAL for Feb. 1916. M.M.B.

1931—CHARGING CURRENT OF TRANSFORMERS—Sometimes when large transformers are connected to a source of power, they draw considerable current momentarily, and give an audible grunt. This condition is usually explained by saying that the oil switch closed on the crest of the e.m.f. wave. Since it appears that the sum, at any instant, of three voltages displaced 120 degrees is zero, will you give an explanation of this rush of charging current? R.B.G. (MONT.)

The rush of current causing an audible sound when connecting transformers to a live bus is due to the core of the transformers having high flux densities when the circuit is closed at certain points of the voltage wave. During normal operation, the voltage and flux wave of any one phase are indicated at *A* in Fig. (a). Now, if the switch is closed at point 1 in Fig. a, the flux instead of having a maximum value above the line will be zero. For the next half cycle of voltage, the flux, instead of changing from maximum on one side of the line to a maximum on the other side, must make the same variation but start from zero as indicated at B. During the next few cycles, the flux wave works its way back to a symmetrical position. During the flux transient, a large magnetizing current will flow and it is the effect of this current that is audible. J.F.P.

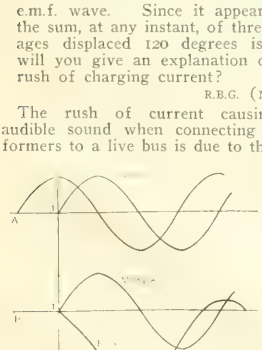


FIG. 1931 (a)

1932—MULTIPLIER FOR INTEGRATING WATTHOUR METER—I have a three-phase watthour meter having five ampere current coils and 110 volt potential coils. This meter is calibrated for use on a 550 volt circuit i.e., potential coils will be connected through a 5:1 potential transformer. I want to connect this meter to a 2200 volt circuit through current and potential transformers by connecting the potential coils through a 20:1 potential transformer as this meter is calibrated for 550 volts. What will the multiplier be when connected to the 2200 volt circuit? For example say the above meter had a potential winding of 550 volts and we had no 550 to 2200 volt potential transformers and connected up the meter through a transformer arrangement as shown in Fig. (a) would this be considered good practice? What would the multiplier be in this case? R.H.N.L. (CAN.)

A 5 ampere, 100 volt polyphase watthour meter designed to be used with 500-100 volt potential transformers would be equipped with a 5 kw counter, provided the current transformer ratio is 5:5. If the meter is to be used with 2000 to 100 volt potential transformers, the meter should be equipped with a 20 kw counter. The multiplier would, therefore, be 20 ÷ 5 or 4 if the 5 kw counter were not replaced by a 20 kw counter. The multiplier for the connections shown in Fig. (a) would be 4. The connections shown in Fig. (a) could be used if only a 500 volt meter were available. It would not be considered good practice to use such a connection because of the necessity of using the extra potential transformer, and also because, in addition to the extra losses in the second transformer, both voltage and ratio losses, the regulation of the second transformer, operated inverted, would be off by twice the compensation of the transformer. A.R.R.

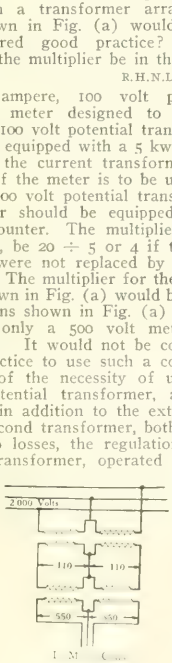


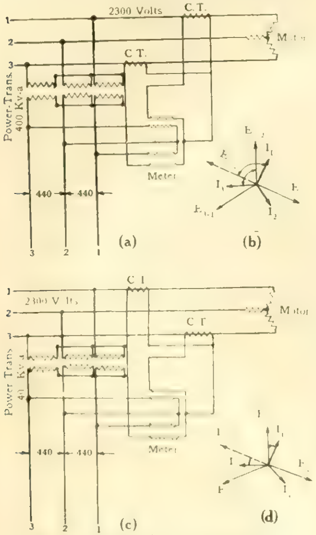
FIG. 1932 (a)

1933—USE OF EMERY CLOTH ON COMMUTATORS—Is there any valid objection to the use of emery cloth for smoothing commutators in place of sand paper which is usually recommended? R.R.C. (PA.)

In the early days, sand paper was found better than emery for smoothing commutators, due to the fact that the fine emery lodged in the commutator copper and in the brush faces which seemed to have a harmful effect. This, to a certain extent was due to the use of oil, grease and lubricating compounds, which were quite common in those days, the self-lubricating type of brush being quite rare. The sand paper, being coarser than the emery, did not tend to form a coating over the brush surface. However, when it comes to a perfectly dry commutator, and brushes with natural graphite lubricant not much difference will be found between emery and sand paper. The higher commutator speeds of the present time also tend to throw off dirt and dust. However, as all experience has pointed toward the sand paper being somewhat better than the emery, we would suggest that this practice be adhered to, although in emergency, as for instance, when emery is available and sand paper is not, it would probably be safe to use the emery cloth. There may have been some difference, in the olden times, between emery and sand paper, in the lodgement of particles in the mica between bars. Of course, at the present time, with so many high speed commutators undercut, this possible difference is of less importance. Emery is used on small high-speed machines such as head light turbo generators, with better success than is obtained with sand paper. Conditions are hard things to get away from, especially when they are convenient and adaptable to the proposition in hand. Sand paper is certainly more easily available than emery cloth and cheaper to use where only a smoothing operation is required. Sand paper is essential for slow-speed machines, but in high-speed machines there is a chance to throw off the carborundum particles and no trouble would be encountered with the emery. B.G.L. & E.I.C.

1934—SWITCHBOARD METER CONNECTIONS—Please give your advice on the following problem:—As shown in Fig. a, the current transformers for metering the power to the 2300 volt motor are in the 2300 volt line, while the potential is taken from the 440 volt side of a three-phase star-connected power thansformer. There does not seem to be any arrangement of the potential connections that will cause the meter to read accurately. Is this due to the fact that the current transformers are in delta, and the power transformers in star? Will you please give the correct vector diagrams showing the relation between the currents and potentials in the meter coils with this connection and state if accurate metering connections are possible with this arrangement, or must potential transformers be installed to get correct results? S.H.B. (N.Y.)

The connections shown in Fig. a are incorrect, due not to the different methods of connecting the transformers but to incorrect connections to the meter itself. The vector diagram, Fig. b, corresponding to the connections in Fig. a, will explain this. From this the current and voltage in each element of the wattmeter are 90 degrees out of phase with each other at 100 percent power-factor. Therefore, the connections as shown in Fig. (a) are correct (for balanced loads only) for measuring the wattless component in the circuit, and not the power component. The proper diagram of connections for the wattmeter is as shown in Fig. (c). As previously stated, however, it is not advisable to connect a wattmeter as shown in Fig. a, where the current and potential coils of the meter are connected to different sides of a power transformer. The result of such a connection is to introduce errors into the meter indications other than those inherent in the meter itself. Thus, when so connected, the power transformer, when loaded, introduces both a ratio and a power-factor error, which cannot be compensated for and which are proportional to the load on the transformer. In the case of an instrument transformer, however, the transformer itself is compensated for all load placed on it, and hence registers correctly within narrow limits of error. As the only object of such a procedure as the above is to avoid the use of potential transformers, we would suggest that the application of instrument potential transformers would give sufficiently increased accuracy, to the indications of the meter, to warrant their application. H.P.S.



FIGS. 1934 (a), (b), (c) and (d)

1935—**Three and Four-Wire Distribution Circuits for Scott-Connected Transformers**—We have a bank of Scott-connected transformers rated at 750 kv-a, 22 000 volt, three-phase to 480 volts, two-phase. The load consists of welding machines and is unbalanced between the two phases. Is there any advantage gained in using four-wire distribution over three-wire distribution, the common wire being increased 1.41 percent in cross-sectional area? H.D.H. (OHIO)

Three-wire distribution has the disadvantage that a load on one phase affects the voltage on the other phase. However, when both phases are used to supply welding machines, small variations in voltage are not seriously objectionable. To get the same performance with four-wire distribution will require more copper, since the 141 percent wire would have to be replaced by two 100 percent wires. J.F.P.

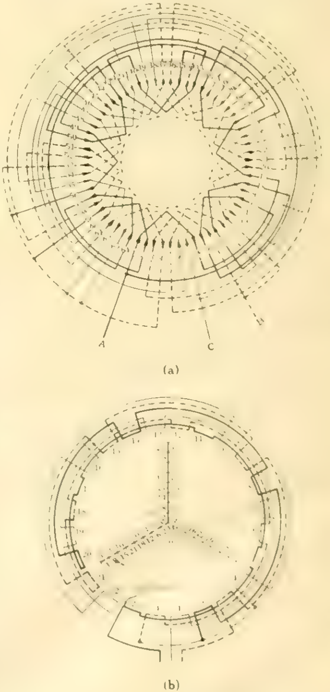
1936—**Air Circuit Breakers**—Recently we purchased several two and three thousand ampere, direct-current air circuit breakers from the General Electric Co., and upon close inspection I find that the iron frame of the breaker, as well as the bridge contact, carries current. A doubt exists in my mind as to the accurate operation of circuit breakers of this type as compared with those of the insulated bridge type. Is it proper to assume that only a partial saturation of the iron frame is possible under these conditions? However, I know of instances where excellent results are obtained from the above mentioned type of circuit breakers. Assuming that due to some mechanical defect the bridge contact (of one of these non-insulated bridge type) broke down, would not the magnetizing effect on the armature be partially decreased? D.F.Z. (KANS.)

The iron magnetic circuit which surrounds the lower stud head of the 2000 and 3000 ampere direct-current air circuit breakers of the General Electric Company is insulated from the stud head. Consequently all of the current which passes through the circuit breaker passes through the contact between the laminated copper brush or bridge and the lower stud. A small portion of the total current passes through the iron frame but this does not affect the total amount of current which links the overload magnetic circuit. In other words the total current through the circuit breaker links the magnetic circuit, and so the magnetizing effect on the overload armature is not affected by good or bad brush contacts. G.G.G.

1937—**Connections for Welding**—We have a two-phase, 440 volt power circuit from which we wish to take off a single-phase, six volt circuit for a welding machine. Can we use a two-phase primary, single-phase secondary transformer for this circuit so as not to unbalance the two-phase circuit? If this is a practical transformer would the frequency of the secondary circuit be changed? The welding machine is of the butt weld type and requires about 50 kv-a at six volts. R.H.A. (OHIO)

It is possible to use one two-phase transformer or two single-phase transformers, as indicated, but the two-phase circuit will be unbalanced about the same amount as if the total load was taken off one phase only. If 50 kv-a, one-phase load is required to be taken off between the phases, the transformer capacity must be increased 41 percent and approximately 71 percent of the load will be taken from one-phase at a lagging power-factor of 71 percent (assuming 100 percent power-factor load) and another 71 percent of the load will be taken from the other phase at a leading power-factor of 71 percent. The percent regulation of one phase will therefore be increased and of the other decreased. Assuming a single-phase load of 71 percent power-factor, 71 percent of the load will be taken from one phase at unity power-factor and another 71 percent of the load will be taken from the other phase at zero power-factor. The frequency of the secondary circuit will not be changed. If the single-phase load is only a small percentage of the total load, we should recommend taking the load from one phase only. See No. 958, September 1913; 1010, January 1914; 1080, August 1914. The only practicable scheme for balancing a single-phase load on a polyphase system or vice versa is to use a rotating machine such as an induction motor running idle as a phase converter. See No. 504, November 1910, or article on Single-phase Loads from Polyphase Systems, by B. G. Lamme in the JOURNAL for June 1915, p. 261. H.F.

1938—**Unequal Grouping**—Fig. (a) shows the arrangement of a winding for a 50 hp, three-phase, 60 cycle, 220 volt, 870 r.p.m. induction motor. Each coil consists of 10 turns of 3 No. 10 d. c. c. wires in parallel. The rotor is of the squirrel-cage type and has 55 bars. Is the arrangement as shown as good as can be had on such a winding? About how much will the currents in the various phases differ in value? W.C.S. (QUEBEC)



FIGS. 1938 (a) and (b)

Sixty-four slots will not give a symmetrical 8 pole, three-phase winding as there will be 8 slots per pole. 8 divided by 3 = 2⅔ slots per phase. However, it is possible to get a balanced unsymmetrical winding on the machine by leaving one coil dead, (not connected, both stubs taped up). To do this put half the number of series turns in the slots that you have specified. Then connect the coils in pole, phase groups and connect these groups, in series star. The winding will consist of 5 turns, each of 6 No. 10 wire, or the equivalent, with a throw of 1-7 connected according to Fig. (b). This will give a balanced winding and there should be no unbalanced currents. T.P.K.

1939—Hot Wire Ammeter and Weston Meter as Slip Indicators—What are the objections to using a hot wire ammeter, connected in series with the rotor to measure the slip of an induction motor, the swing of the needle showing the difference in frequency between the rotor and stator. In this case the meter measures the rotor current and the needle indicates the beats of the slip, which to my opinion is a simpler method than the vibrating reed slip indicator described in the Journal for April, 1920. Recently I tried to measure the slip of a motor with a 10 ampere Weston ammeter connected across the secondary of a current transformer, placed in the rotor circuit, but found that the needle of the ammeter did not indicate the beats of the slip. Explain the merits and faults of using the hot wire meter as a slip counter and why the Weston meter did not indicate the slip. In the first case the stator was two-phase and with the Weston meter the stator was three-phase.

J.E.M. (Mich.)

The earlier stroboscopic methods for determinating the slip of induction motors were limited to the rate at which the tester could count the apparent oscillations. Not only does this same objection hold true with the use of the hot wire ammeter, but as the percentage of slip increases the amount of deflection of the hot wire ammeter needle decreases and tends to make the task of counting the beats of the slip all the more difficult. A more serious objection to the use of the hot-wire ammeter for measuring the slip of an induction motor, even though one could count the beats of the needle accurately, is the error in percent slip which is introduced by assuming that the frequency of the power circuit remains constant at a certain value. With this scheme it is necessary that the actual frequency of the current supply be known and that it remain constant throughout the period of testing. Slight changes in the frequency of the power circuit would change the synchronous speed and the percent slip obtained in this manner would then mean nothing at all. With the vibrating reed slip indicator the vibrations of the synchronous reed used for comparison with the speed of motor, are produced by an electromagnet which is connected to the same power circuit as the motor. It is obvious then, since the frequency of the vibrating reed is always the same as the frequency of the motor supply current, that the accuracy of the percent slip determined will not be effected by any changes in frequency of the power supply which may occur during the test. The Weston meter would not show any deflection because it was being used in conjunction with a current transformer on such a low frequency as the slip of an induction motor gives. In such a case we would advise the use of a direct-current millivoltmeter with a sufficiently large shunt to carry the rotor current.

E.I.C. & M.B.

1940—Electrostatic Ground Detector—Fig. (a) shows three 200 watt, 6000 to 100 volt potential transformers connected star-star to indicate grounds on a 6600 volt station bus. Would not a three-phase electrostatic ground detector be just as satisfactory as the transformers for this service, and cheaper, both in first cost and consumption of energy?

R.B.G. (Mont.)

The most general types of ground detectors in use at the present date are the electrostatic glow meter, the electrosatic ground detector and various methods using transformer schemes. The electrostatic glow meter is the simplest and has the smallest space factor, the transformer schemes having the greatest disadvantage in this respect. The dependability for continuous service of the electrostatic glow meter is much greater than either of the other two methods. The electrostatic glow meter has no moving parts and is so constructed that it has no parts that are subjected to wear, thus giving it practically an indefinite life with proper care.

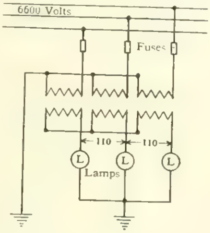
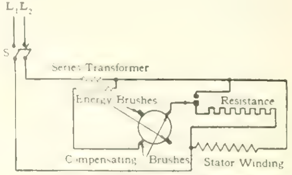


FIG. 1940 (a)

The electrostatic ground detector has only two moving axes making it a very dependable method. The transformer scheme shown has no moveable parts, but it is liable to be put out of commission by having a lamp burn out or a fuse blow out. The relative prices for these three schemes are as follows:—The electrostatic glow meter 1.4, the electrostatic ground detector 1.3, and the transformer scheme as shown 2.0. This does not include mounting and wiring. The power consumption of either the electrostatic glow meter or the electrostatic ground detector is practically zero, while the power consumption of the transformer scheme is a material amount, thus causing a continuous expense. J.V.H.

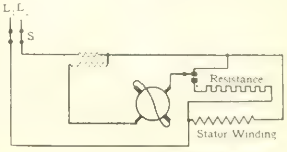
1941—Dynamic Braking on a Single-Phase Motor—Can you explain how the dynamic braking affect is obtained on a single-phase, brush shifting, variable speed motor. On the off position of the controller there is a closed circuit including armature, compensating brushes, stator winding, part of series transformer and resistance coils, as shown in Fig. (a). Why is part of this transformer included in this braking circuit? What are the functions of the compensating brushes and series transformer when motor is running? A. R. (Ohio)

In answering this question it is best to show the simplest two-pole arrangement, which is equivalent to the brush arrangement of the actual motor. Such a two-pole arrangement is shown in Figs. (a) and (b). It will be seen that the connections for dynamic braking are exactly the same as for a direct-current series motor connected for dynamic braking. Actually the braking current is direct-current, the same as it would be in a direct-current motor, the energy brushes being idle during the braking period. The resistance in the braking circuit holds the current down. The secondary of the series transformer is included in the braking circuit, because it simplifies the control and it does no harm otherwise. The purpose of the compensating brushes is to give power-factor compensations. The latter is obtained by deriving from the motor armature a wattless voltage induced between the compensating brushes and by introducing such a voltage into the stator circuit in series with the stator field winding. The series transformer simply has the purpose of adjusting the current and voltage of the exciter brushes so as to adopt them to the stator circuit. R.E.H.



Connections for Braking

(a)



Running Connections

(b)

FIGS. 1941 (a) and (b)

1942—Selections of Oil Circuit Breakers—How may I determine the right size of an oil circuit breaker for voltage and for current, assuming we want a switch for a 15 000 kv-a, three-phase, 22 000 volt transmission line? How will the above selection be affected if the voltage was only 13 000 volts in place of 22 000 volts? Is the capacity of the line an important item in the selection of the oil switch, or would you assume the oil circuit breaker to be opened at full load, which would be the worst condition, according to my opinion?

M.W.D. (New York)

Circuit breakers are rated as to normal voltage, current and frequency, and interrupting capacity. The voltage of the circuit breaker should be equal to, or greater than the voltage between lines of the circuit on which it is to be applied. The current rating should be equal to, or greater than the greatest continuous load current in the circuit. If the line voltage was changed from 22 000 volts to 13 000 volts and the *continuous load current remained the same,* the circuit breaker for the 22 000 volt line would operate satisfactorily with 13 000 volts

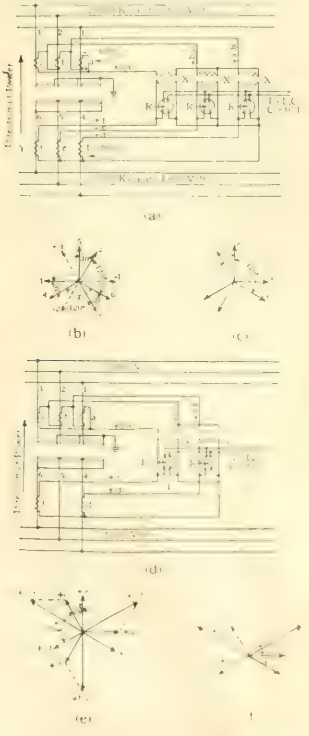
However, if the continuous load current was increased to exceed the current rating of the circuit breaker, the latter would become overheated. Circuit breakers are commonly rated for 60 cycles and on 25 cycles will carry about 20 percent more current with the permissible temperature rise of 30 degrees. The rated interrupting capacity should be greater than the circuit breaker will be required to open under the worst conditions, i. e., short-circuit just beyond the circuit breaker. This factor makes the size depend on the capacity of the line. For further information reference may be had to the A. I. E. E. Standardization Rules, par. 367 to 374 and "Rating and Selection of Oil Circuit Breakers", by Hewlett, Mahoney & Burnham in *A. I. E. E. Proceedings* for Feb. 15, 1918. L.R.G.

1943—DIFFERENTIAL RELAYS—Does Fig. (a) show the correct series transformer connections for a differential relay system around a star-delta transformer? (b) Please give vector diagram and explain the action of differential relays, (c) ratio of transformers at "X" and how obtained. (d) Also give correct solution and vector diagram if only two series transformers are used at *Y*.
E.P.B. (NEW YORK)

Fig. (a) gives the series transformer connections for differential relay protection of three-phase transformers using three differential relays. (b) In order to bring the secondary currents of the series transformers in phase it is necessary to connect them star-delta, as the power transformers are delta-star. The vector relations in Figs. (b) and (c) may readily be followed from Fig. (a). Fig. (e) results when the currents in Fig. (c) are added to obtain the currents in the windings of the transformers at *X*. It will be seen that the currents in the primary and secondary of each of the *X* transformers are 180 degrees out of phase, which is the desired relation. Assuming the condition that the secondary currents of the main series transformers are, say, five amperes on both the low- and high side of the power transformers, the current in the low-tension side of *X* will be 0.575 × the current on the high side. Under this condition no current will flow through the relay windings, and hence there will be no action of the relays. If, however, trouble developed in one of the main transformers, more energy would be delivered to the primary than would be taken out at the secondary (neglecting normal internal losses) and the currents *4*, *5* and *6* would bear a new relation to *1*, *2* and *3*. This would cause additional current in *d*, *e* and *f*, and this additional current must flow through the winding of the relay of the transformer in trouble, causing the relay contact to close, opening the breakers on both sides of the transformer bank. (c) At normal load of 25 000 kv-a, the primary current at *4*, *5* and *6* is 2270 amperes and secondary current at *1*, *2* and *3* is 1000 amperes. Under the conditions given, the current in the secondary of the series transformers, *d*, *e* and *f* will be $2270 \times \frac{5}{1600} = 7.1$ amperes and at *a*, *b* and *c*, will be $1000 \times \frac{5}{600} = 8.33$ amperes. It is necessary to have the ampere-turns on the lower and upper sides of *X* equal and, as the current on the low side is 7.1 amperes and the current on the upper side is 1.73 × 8.33, the ratio of transformation at *X* will be,—

$$\text{Ratio} = \frac{8.33 \times 1.73}{7.1} = 2.03$$

(d) When two transformers are used at *Y*, the circuit shown in Fig. (d) must be used. The vector diagram in Fig. (e) shows the current relations obtained from Figs. (a) and (b). It may be seen that current *c-a* in Fig. (e) is 180 degrees out of phase with current *f* and $\sqrt{3}$ times the value of *f*. Ordinarily two series transformers will be quite satisfactory, as in Fig. (d) this being the most common method. Three transformers at *Y* necessitates one more series transformer and an extra relay, but offers slightly better protection by the additional relay contact in case of the remote possibility of failure of the first two relays. A.K.



(a)

(b) (c)

(d)

(e) (f)

FIGS. 1943 (a), (b), (c), (d), (e) and (f)

1944—RECONNECTING AN INDUCTION MOTOR FOR A SINGLE-PHASE GENERATOR—We need a 10 kw, 220 volt single-phase alternating-current generator, but as we cannot get delivery from the manufacturers in a reasonable time, we are thinking of using a 15 hp, 550 volt, three-phase, 60 cycle, 900 r.p.m. induction motor. The winding is series star, 72 coils, throw 1 to 10. Can the whole winding be used for a single-phase connection? We would construct the rotating field. How wide should the face of the poles be? The stator has a bore 14 inches diameter, 4 1/2 inches wide. Could you give an estimate of the field winding, size of wire, and number of turns? Do you think we could expect satisfactory results?
J.A.W. (SASKATCHEWAN)

If the motor in question is a slip-ring motor direct-current might be supplied to the rings to excite the field. A new rotor could be designed for this motor to operate as a synchronous machine if all the data were available. As the question stands, however, there is not enough indicated to make more than a rough guess as to conditions of the magnetic paths on which to base an estimate. Attached is a sketch of a section of rotor and pole, which might be made of cast steel. The sketch indicates that the poles and spider are cast in one piece and then a pole-shoe bolted on after the winding has been put in place. For a winding try 220 turns of No. 14 double cotton covered wire. This should carry about 17 amperes at 125 volts as a maximum. If the armature winding is connected in two parallels and operated at reduced voltage with a corresponding reduction of rating the present winding might be used. When a machine is operated on a single-phase load, the current per terminal cannot be increased to any considerable extent beyond that for three-phase operation; the rating of a machine for single-phase operation will be reduced to something like 60 percent of its three-phase rating. This question is discussed in detail in an article by B. G. Lamme on "Comparative Capacities of Alternators for Polyphase and Single-Phase Currents" in the JOURNAL for August, 1911, p. 672. E.B.S.

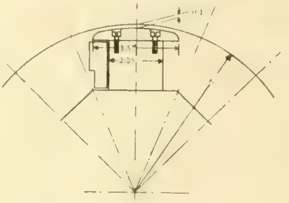


FIG. 1944 (a)

1945—DIAMETRICAL CONNECTION—A six-phase rotary converter is fed diametrically by three single-phase transformers. In case one transformer burns out, how can I operate the rotary converter on the remaining two?
M.S.E. (PENNA.)

When three transformers are connected delta, high-voltage, to diametrical low-voltage for operating a six-phase rotary converter, the operation may be continued in the event of one transformer burning out without change in connecting except to disconnect the defective unit, by reducing the load to 57.7 percent of normal. This is necessary to limit the heating in the transformers and in the converter armature. Trouble may be experienced in starting if the converter is started from the alternating-current side, owing to the reduction in torque when starting with unbalanced voltages. This can be overcome by increasing the starting voltage, as can often be done by changing from a one-third to a two-third voltage starting tap. M.E.S.

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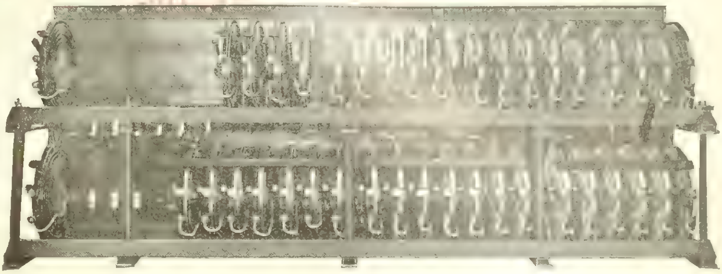
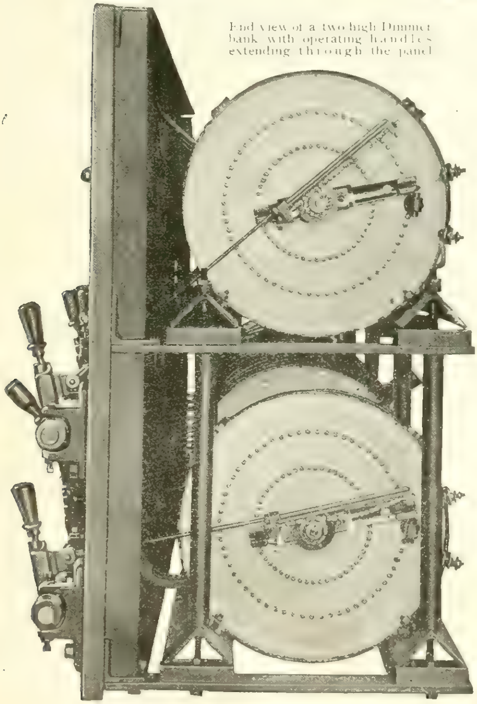


Back view of Dimmer Panel showing arrangement of [illegible] plate



End view of a two high Dimmer bank with operating handles extending through the panel

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NATIONAL SAFETY SECTION

OPERATING RULES FOR BOILERS

(*Continued*)

CLEANING BOILERS

The blow-off valves, stop valve in the "goose neck" next to the steam header, and the stop valve in the feed pipe next to the feed header, should all be locked shut and the keys retained in the possession of the man in charge of the subsequent cleaning operations. Place on the handle of all of the above valves a suitable sign as follows: "MAN INSIDE BOILER: DO NOT TOUCH." Manhole covers may be then removed and the boiler opened up for cleaning. It should be an invariable rule that the man who enters the boiler for the purpose of inspection, and who is in possession of the keys locking the above mentioned valves, must give the final assent for the return of the manhole covers to their places. Previous to entering the boiler it is advisable to determine whether there is any gas or bad air present, by passing a torch or candle inside.

For locking the valves as advised above, the following method is suggested: Make a loose cover for the hand wheel of the valve out of sheet steel. This cover is simply a circular box made in halves and hinged at one side, with a hole in the bottom for the valve stem. On the side opposite the hinge an arrangement is made for attaching the lock, so that the box can be locked shut. This box can be painted bright red, with the word "DANGER" in another color. For large steam valves, this box may also have a sleeve extension to cover the valve stem, thus preventing the use of a wrench on the stem of the valve.

CLEANING BOILER SETTINGS

The cleaning of the setting of coal fired boilers should not be commenced until all the flue dust and other material, also the walls of the settings, have been cooled to a temperature where there is no possibility of a man being burned by touching them. The cleaning of gas fired boilers will necessitate an additional precaution in the way of testing the chambers by means of lighted candle or torch to detect the presence of gas or bad air before a man undertakes to operate therein, and, furthermore, the gas valve leading to such a boiler should be locked shut and the key retained in the possession of the man in charge of the [illegible] operations. A sign: "MAN INSIDE BOILER; DO NOT TOUCH," similar to that to be placed on the steam feed and blow-off valves, is to be placed on this valve also.

[illegible] STEAM [illegible] AND OTHER STRUCTURES UNDER PRESSURE

If for any reason, such as blowing out of gaskets, vitration, over-straining of pipes or general deterioration, the joints of steam pipes develop objectionable leaks, the application of wrenches to bolts of such joints while under steam pressure should be absolutely prohibited. If such joints are to be repaired it should be done after the pressure has been removed from the particular section where the trouble occurs. If the [illegible] a fire tube boiler develops leaks at the tube sheet, expanders should not be applied to the ends of the tubes while the boiler is under steam pressure. If a leak develops at any part of the sections of a boiler, whether in the headers to which the tubes are attached or at a riveted joint, the use of a calking tool to stop this leak while the structure is under steam pressure should be prohibited. This applies to rivets as well as plates. All such repairs should be made after the steam pressure has been taken off the boiler. If a leak develops at the hand-hole plate or around the tube caps of water tube boilers same should not be stopped by tightening up the bolts while steam pressure is on the boiler. If a leak develops at a manhole cover it should not be stopped by tightening the bolts in the yoke while the boiler is under steam.

STOP VALVE STEMS

Rising stems of valves should not be permitted to become rusty or covered with dirt so that they cannot be moved the full extent of their travel at any time. A periodic inspection, not less than once a month, of all valves, stems, etc., in all the main piping systems about the boiler house is recommended: Too much importance cannot be attached to keeping the valves in such condition that they are always ready for use. Great care should be exercised in using a wrench or bar in opening or closing a valve. The abuse of this means of facilitating the handling of valves may result in damage or accidents to seats, threads, stems, etc.

THE CARE AND USE OF WATER COLUMNS AND TRY-COCKS

Water columns should be blown out completely at least twice every turn. If a gauge glass is fouled internally, so that the water level is not clear, the glass should be cleaned or replaced as soon as possible. If the fouling of the gauge glass occurs frequently, it is due to some characteristic of the water, such as suspended matter, scale solvents, lubricating oil, etc., for which some remedy should be devised. Try-cocks shall be used at least twice every turn, which regular use will keep them in good working order.

TEAM WORK

In every well-ordered department it is the duty of specified workmen to operate certain valves in case of accident. Where there is both direct and indirect control of important valves, team plays should be installed to reach both controls at the earliest moment. Gates and valves are occasionally found depending entirely upon indirect control. Direct control should also be provided.

LAYING UP BOILERS

If for any reason a boiler is to be taken out of service for cleaning, etc., the following procedure should be observed:—

Check the dampers and allow the fires to burn out, at which time the non-return valve will be seated; also close the gate valve in the branch next to the header and open the drains in the "goose neck." Shut off the stop valves in the feed pipe. Rapid cooling sets up undesirable strains in the equipment. Cool as slowly as time will permit. A small amount of air may be passed through the furnace to assist in the cooling. To do this open doors and dampers slightly. After the boiler is cool the blow-off valves may be opened and boiler drained. If for any reason the boilers are to be laid up indefinitely the following precautions should be taken to provide for safe conditions when boilers are again put into service:—

Thoroughly drain the drums and tubes and clean them inside and outside. Then completely fill boiler and replace covers which have been removed. This method is not practicable when boilers could freeze. In such cases, after cleaning boilers dry them thoroughly and place a pan of lime in each drum to absorb moisture. Do not replace manhole covers. Some companies prefer to clean and dry a boiler and then smear the inside of the drums and tubes with a heavy crude oil or fuel oil. This should be put on with a swab, and when putting this on in a drum an electric lamp should be used, and not an open torch. Drums and tubes should be left open. Mud drums, headers, and tube caps should all be cleaned and similarly coated. In all places where freezing may occur, care should be taken to drain water from all parts or fittings, or, where these cannot be drained (as in the case of steam gauges) they should be moved and stood in warm places.

LUBRICATION DATA

The Texas Company is issuing a highly interesting monthly magazine called "LUBRICATION."

This periodical is interesting not only for the valuable material contained in each individual issue, but for the broad gauge plan behind it.

Apparently, it is the policy of The Texas Company to take up in turn the more important industries and after giving a brief outline of the manufacturing processes or the mechanical procedure, to describe the units involved and to discuss the particular or peculiar lubricating problems of these units or their parts.

Some of the industries taken up have been,—textile manufacture, metal cutting, refrigeration and ice making, cement, sugar refining, rubber manufacturing, compressed air, electric street railways.

We understand they have in view articles on the paper industry, machine tools, hydroelectric developments, steam turbines, marine installations, and other articles devoted to the larger divisions of manufacturing or power utilization.

While this magazine is sent out free, the Company makes a provision that the individual requesting to have this magazine sent to him be professionally interested in the use and selection of lubricants, that is, he must be an engineer, master mechanic, executive of a manufacturing or power using concern, a purchasing agent, or engaged in work of a similar nature. "LUBRICATION" is published from the New York Office of The Texas Company which is situated at 17 Battery Pl., New York City.

TOPICAL INDEXES

There are now available for distribution copies of the Ten Year Topical Index of The Electric Journal for the years 1904 to 1913; The Five Year Topical Index for 1914—1918 and the Two Year Topical Index for 1919-1920. The Electric Journal is unique in that all the technical articles which have been published during the past 17 years can readily be located by referring to only three indexes. For the future it is the intention to let the latest indexes run until a five period is covered when a new one will be begun. Any of the above indexes will be supplied at 25c each. Copies of the Two Year Topical Index along with Title Page and Table of Contents can be secured by regular subscribers to the Journal without charge on request.

BOUND VOLUMES OF THE ELECTRIC JOURNAL

Bound volumes for 1920 will be available for distribution about January 1st, 1921. The price is $5.00 per volume in United States and $5.50 elsewhere. Bound volumes are carried in stock from 1907 to date, and orders for any of these volumes will be filled at the above rate. As there is only a limited stock of the older volumes, those desiring them should place their orders promptly, as it will be impossible to secure further books after the present supply is exhausted.

ASSOCIATION I. & S. E. E. MEETINGS

The Pittsburgh Section of the Association of Iron & Steel Electrical Engineers, will be on December 18th when Mr. Gordon Hughes, Truscon Steel Company, Youngstown, Ohio, will present a paper on "Electric Welding—Spot and Butt". The meeting will be held at the Hotel Chatham, with a dinner preceding the meeting.

A meeting of the Chicago Section will be held on December 11th, when Mr. J. P. Wilson, switchboard engineer of the Westinghouse Electric & Mfg. Company will present a paper on "Switchboard Equipment for Steel Mill Power Houses and Sub-Stations."

On December 4th, at a meeting of the Philadelphia Section, Messrs. H. C. Boyton and W. Voiglander, of J. A. Roeblings Sons Company, will present a paper entitled "Instruction in the Care, Use and Inspection of Flexible Steel Cables."

The Cleveland Section meeting will be held on December 13th, subject, "Continuous Rating or 50 Degree Rise Motors," by L. F. Adams, General Electric Company.

PERSONALS

Professor Charles F. Scott, chairman of the department of electrical engineering, Yale University, returned recently from a three months' trip to Italy, where he represented the Western Electric Company in dealing with communication cable location. The particular problem was whether it is practical to run a cable from Milan to Genoa and Turin without interference from railroad and transmission lines. As a result of the summer's work a considerable amount of interesting information with reference to inductive interference and three-phase lines, under Italian conditions, was collected.

Mr. C. B. Merrell, has been appointed district sales manager of the Philadelphia office of the Economy Fuse & Mfg. Company to succeed Mr. E. J. Watson, resigned.

Mr. D. C. Wilson, general sales manager of the Chain Belt Company of Milwaukee has resigned to accept the position of secretary of the Federal Malleable Company, West Allis, Wisconsin, which is an associated concern. He will be suceeded as sales manager by Mr. C. F. Messinger.

Mr. E. I. Chute, who has been in charge of the testing department of the Westinghouse Electric & Mfg. Company at the East Pittsburgh works, has been appointed engineering inspector, and will report directly to Mr. R. S. Feicht, director of engineering.

Mr. W. T. Everett, formerly of the Homewood service department of the Westinghouse Electric & Mfg. Company at East Pittsburgh, has been made assistant electrical service manager, with headquarters at the East Pittsburgh works.

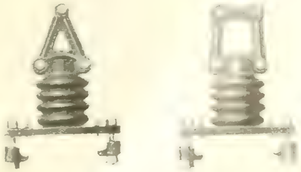
Mr. H. L. Lautenschlaeger, of the purchasing department of the Westinghouse Electric & Mfg. Company at East Pittsburgh, has recently been appointed manager of production of the Geo. Cutter Works at South Bend, Indiana.

Mr. J. M. Barr, formerly of the industrial sales department of the Westinghouse Electric & Mfg. Company, has recently been appointed general manager of the Mechanical Appliance Company of Milwaukee.

Delta Star Electric Company of Chicago have moved their Philadelphia office from 902 to 1333 Real Estate Building.

UNIT TYPE BUS SUPPORTS

The Delta-Star Electric Company, Chicago, Illinois, have developed a "Unit Type" bus bar support which can be clamped to I-Beams from 8" to 24" and used in either upright or inverted positions. The clamps securely grip the I-Beams and after being placed in position are securely locked by means of steel set screws. These "Unit Type" supports are made for all sizes of bus and for all voltage up to and including 33000.



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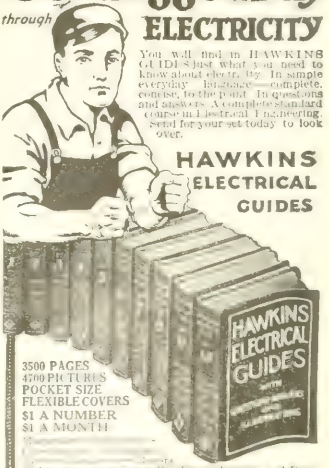

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'Electrical Characteristics of Transmission Circuits"—WM. NESBIT

"Switchboard Meter Connections for Alternating-Current Circuits"—J. C. GROUP

"The Technical Story of the Synchronous Converter"—B. G. LAMME

"Steam Turbines for Mechanical Drive"—IVAN STEWART FORDE

"The Story of the Insulations"—C. E. SKINNER

"Use of Electricity in Metallurgical Processes"—ROBERT M. KEENEY

"The Thermal Storage Demand Wattmeter"—PAUL M. LINCOLN

"Allowable Working Stresses in High-Voltage Electric Cables"—CHAS. W. DAVIS AND DONALD M. SIMMONS

"Regulation and Inductive Effects in Single-Phase Railway Circuits"—A. W. COPLEY

"The Cost of Interruptions of Power to Steel Mills"—E. S, JEFFRIES

"Direct-Current Crane Controllers"—H. D. JAMES

"Methods of Computing Machinery Foundations"—W. H. GILLELAND AND A. H. CUNNINGHAM.

"Secondary Conductors for Electric Furnaces"—EDWARD T. MOORE

"Slip Arrester for Heavy Electric Locomotives"—C. C. WHITTAKER

"Electrical Refrigeration"—C. J. CARLSEN

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